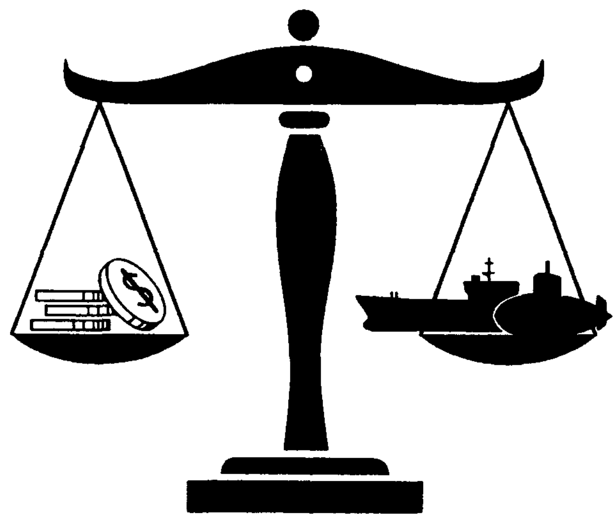
29th ANNUAL TECHNICAL SYMPOSIUM

1992



ACHIEVING AFFORDABLE PERFORMANCE

THURSDAY, MAY 28, 1992
SHERATON CRYSTAL CITY HOTEL
ARLINGTON, VIRGINIA

CODE OF ETHICS

The Association of Scientists and Engineers of the Naval Sea Systems Command has as its objectives to promote the best interest of the Government of the United States of America, to promote the professional development of the membership, to maintain high standards of professional ethics and competence, and to foster good fellowship and cooperation. When engaged in Association activities, the standards by which ethical conduct shall be measured are delineated in the following ASE Code of Ethics:

Article I. ASE members shall place the interest of the United States Government, the Naval Sea Systems Command and the Association above any personal interests.

Article II. ASE members shall actively support the Command's policies on EEO, sexual harassment, and other non-discrimination programs.

Article III. ASE members shall limit use of government resources to levels acceptable to the Command when preparing and distributing Association correspondence or generating physical displays.

Article IV. ASE members shall protect the integrity of proprietary, contractual or classified information in performance of Association business.

Article V. ASE members shall conduct themselves in such a manner as to avoid behavior that is, or might be perceived to be, illegal, improper or unethical.

ASSOCIATION OF SCIENTISTS AND ENGINEERS
OF THE NAVAL SEA SYSTEMS COMMAND
Post Office Box 15864
Arlington, Virginia 22215

May 28 1992

On behalf of the Executive Board and the general membership of the Association of Scientists and Engineers of the Naval Sea Systems Command, I welcome you to our 29th Annual Technical Symposium. In 1991, ASE took a bold step and not only changed the Symposium time but revitalized and energized this core ASE activity. This year's program promises to be among the best! Although you will note that this year is not business as usual. We too are facing the stigma of declining budgets and the frills of an ASE momento have been eliminated so that we can continue to bring you this quality ASE Symposium Paper Package without a price increase.

The Professional Development Committee has put together a strong technical program covering the broad spectrum of Command responsibilities. The theme this year is "ACHIEVING AFFORDABLE PERFORMANCE" and we have included a panel discussion in technical session 1 on "Affordability" to highlight the importance of this issue within the Command. The paper topics in the technical sessions range from insensitive munitions to HM&E and combat systems interfaces, corrosion control to environmental monitoring and guidance systems, decision making under casualty to survivability management and ship design tools to cost modeling; truly a program structured to meet the objectives of the Association as well as the mission, vision and guiding principals of the Command.

At the luncheon today Vice Admiral Kenneth C. Malley, Commander Naval Sea Systems Command, will provide a "View From The Bridge" and set the course for the future. Vice Admiral J. Paul Reason, Commander, Naval Surface Force, U.S. Atlantic Fleet, will be our luncheon speaker. During the luncheon, Mr Paul Anthony will be our Master of Ceremonies.

The ASE Symposium Committee has done a superb job in planning and preparing for this event. They have once again met the challenges and have emerged successful. We are proud to have had the opportunity to serve our membership, our profession, and our Command.

Elias R. Ashey
Elias R. Ashey
President

NAVAL SEA SYSTEMS COMMAND

MISSION

Our mission is to transform military requirements into naval capabilities through research, development, engineering, design, acquisition, modernization, maintenance and logistics support of effective ships, systems and munitions. This enables our sailors and marines to conduct prompt and sustained worldwide maritime operations.

VISION

Our vision is a topnotch team of NAVSEA activities which has the full support and confidence of our customers and a deserved reputation for excellence.

GUIDING PRINCIPLES

- Provide the highest quality ships, systems and munitions which are safe, affordable, supportable and delivered on schedule.
- Listen to our customers and base decisions on best available information with full consideration of their impact on all concerned.
- Treat people with courtesy and respect, provide a safe and efficient work environment, foster equal opportunity, and recognize noteworthy contributions.
- Build and sustain relationships based on competence, teamwork, career development, and the highest standards of integrity.
- Develop and maintain effective relationships with contractors by dealing in an open, fair, and cooperative manner consistent with law, regulation and the public trust.
- Ensure effective and responsible use of people, money, facilities, equipment and time.
- Conduct all activities in an environmentally responsible manner.
- Achieve total quality through continuous improvement of processes and products.

CONTENTS

Ship Construction Cost Modelling Using DAES

Mr. Peter Antaya
Mr. Bob Venus
Cost Estimating and Analysis Division
(SEA 017)
Naval Sea Systems Command

May 1992

Approved For Public Release
Distribution Unlimited

The views expressed herein are the personal opinions of the authors and are not necessarily the official views of the Department of Defense nor the Department of the Navy

Abstract

With the demands for accuracy in the prediction of cost expenditure and growth in these times when the budget is continually being constrained, managers are searching for tools which will assist them in monitoring their contract expenditures. Utilizing statistical modeling, simple linear regression and polynomial regression, expenditure curves have been determined for specific ship classes as a percent of budget over time. Potential applications include identification of optimal build schedules and prediction of cost growth over contract life. Analysis is based on data obtained from the Defense Acquisition Executive Summary (DAES) reports and represents an aggregate of ship contracts by class.

List of Figures

List of Tables

ABBREVIATIONS

ACWP	Actual Cost of Work Performed
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
CBB	Contract Budget Base
CG	Guided Missile Cruiser
CPA	Cost Performance Analysis
CPI	Cost Performance Index
CPR	Cost Performance Report
DAES	Defense Acquisition Executive Summary
EAC	Estimate at Completion
FFG	Guided Missile Frigate
FFP	Firm Fixed-Price
NAVSEA	Naval Sea Systems Command
NCA	Naval Center for Cost Analysis
PM	Program Manager
SPI	Schedule Performance Index
SSN	Submarine, Nuclear-Powered

INTRODUCTION

Navy Program Managers (PMs) need quick recognition of potential cost growth or schedule slippage to successfully manage contractor performance. The sooner a potential problem in contract execution is recognized, the more time available and the greater the options for resolution. This study attempts to review historical expenditures on shipbuilding construction contracts for individual ship classes, determine standard expenditure equations for each ship class, and discuss possible uses of expenditure as early indicators of contractor cost at completion.

The PM has numerous sources of information available for use in evaluating contractor performance. One source is the return cost data provided in Cost Performance Reports (CPRs). The information provided in a CPR includes the actual cost of work performed (ACWP), the budgeted cost of work performed (BCWP), the budgeted cost of work scheduled (BCWS), and the contractor's estimate at completion (EAC). Performance trend analysis techniques using cost and/or schedule performance (i.e., CPI and SPI), while extremely useful, are not always accurate predictors of ultimate cost and schedule performance when applied in the earlier stages of a contract. Typically, cost and schedule problems are not apparent until the contracted effort has progressed 40% or more. As a result, performance trend analysis performed during the first 40% of the contracted effort may understate cost and schedule problems.

This study identifies historical expenditures for the follow ships of the CG-47, FFG-7, and SSN-688 ship classes, and examines the relationship between these expenditures and cost at completion in the belief that significant deviation from the Naval Ship Expenditure Curve may be an indicator of potential cost or schedule problems. Used in combination with existing performance trend analysis techniques, this information should enhance the PM's ability to assess contractor performance throughout execution of a given contract.

OVERVIEW

This study utilized earlier research and database development by Ms. Donna Lee of NAVSEA 017. The concept of reviewing expenditures for major shipbuilding programs was initiated by Dr. Tzee-Nan Lo of the Naval Center for Cost Analysis (NCA). Early research was supervised by Dr. Lo and Mr. Ron Schnepper of NCA.

Return cost data was collected from Defense Acquisition Executive Summary (DAES) Reports on the CG-47, FFG-7, and SSN-688 classes (16 January 1991 submit).

Using contract start and completion data available in the DAES reports, expenditures were plotted against work complete. Because contract lengths (contract start to projected completion date) vary, it was necessary to normalize the time variable by restating

time elapsed as a percent of total contract length. To normalize for differences in ship quantities between contracts and baseline changes during production, cumulative expenditures were determined as a percentage of the contractor budget base (CBB) at contract award. A linear relationship was developed between time elapsed and accumulated expenditures (as a percentage of the original CBB) for the CG-47, FFG-7, and SSN-688 classes ($R^2 > 0.80$). This effort was further refined into a polynomial regression equation more accurately reflecting historical expenditure profiles ($R^2 > 0.95$).

DATA SOURCES

The source for return cost data used in the study is the Defense Acquisition Executive Summary (DAES) Report which consists of contractor return cost data and PM program and cost assessments submitted quarterly to OSD for all major DoD programs. The DAES reports were used as the source of the study because they are the information management tools established in DoDI 5000.50 to facilitate acquisition oversight responsibilities for the Defense Acquisition Executive and to satisfy periodic reporting requirements for major defense acquisition programs in DoDI 5000.2. DAES reports include only summary level cost performance information. To further refine the analysis, the PM could extract additional data from other available sources (e.g., CPRs, CCDRs, SUPSHIP, shipyards). From the DAES reports, a historical cost database including ACWP, BCWP, BCWS, EACs (Contractor and PM), and the CBB was developed for the CG-47, FFG-7, and SSN-688 classes. These terms are defined as follows:

BCWS (Budgeted cost of Work Scheduled)

Effort (in dollars) budgeted by the contractor to perform work scheduled. At completion, the cumulative BCWS is equal to the Contract Budget Baseline (CBB).

BCWP (Budget Cost of Work Performed)

Effort (in dollars) budgeted for work completed. If the contractor is on schedule, the BCWP equals BCWS; if the contractor is behind schedule, the BCWP is less than the BCWS. By definition, BCWS equals BCWP at contract completion.

ACWP (Actual Cost of Work Performed)

Effort (in dollars) expended to complete actual work performed. Differences from the BCWS and BCWP will result if the contract is behind or ahead of schedule, or if actuals exceed or are less than the budgeted effort for work performed.

CBB (Contractor Budget Base)

The sum of the negotiated cost and the estimated cost for authorized, unpriced work for the contract.

EAC (Estimate at Completion)

Projected total contract cost at completion.

APPROACH

The expenditure curves developed relate cumulative expenditures (measured as a percentage of the CBB at contract award) to the percent of expected contract duration (measured as the percentage of time elapsed between contract award and completion). This approach was used to normalize the differences in contract lengths.

Contract expenditures (ACWP) are measured as a percentage of the CBB at contract award. This unit of measure was utilized to normalize expenditures against a common baseline, the CBB, to permit comparisons across contracts. Because the CBB at contract award is being utilized, cost growth due to baseline changes cannot be distinguished

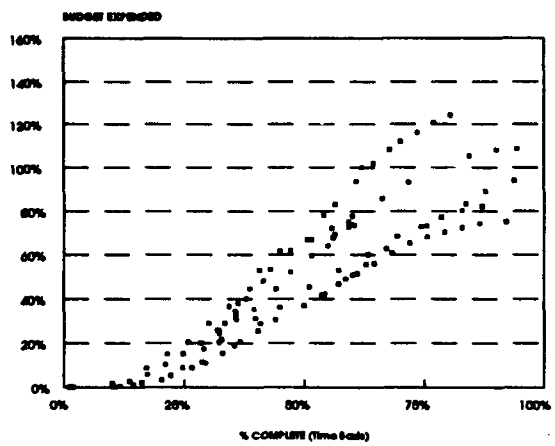


Figure 1 - CG-47 Budget Expenditure

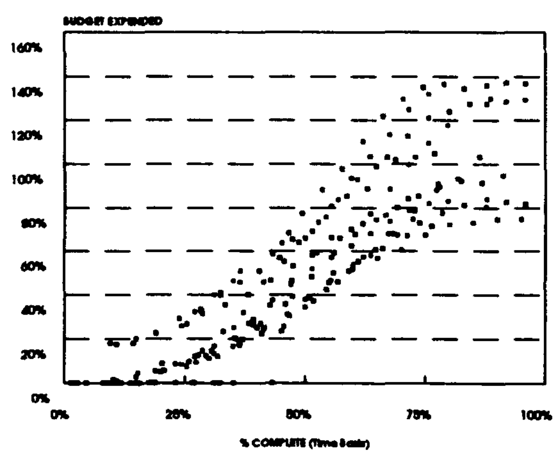


Figure 2 - FFG-7 Budget Expenditure

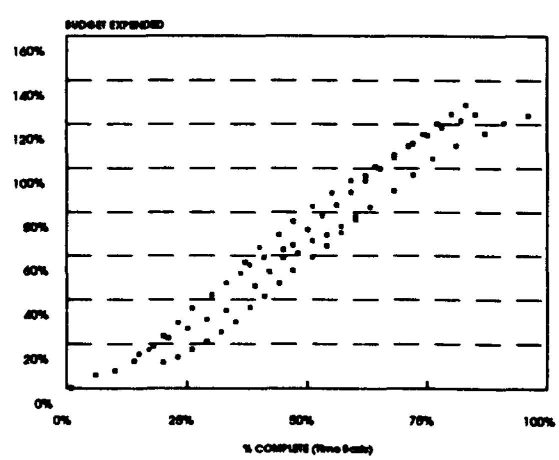


Figure 3 - SSN-688 Budget Expenditure

TABLE 1: Data Sources

Ship Class	Hull #'s
CG-47	48,54-73
FFG-7	8-16,19-28,30,31,33,36-43
SSN-688	754-767,769,770,772

from overrun. However, the intent here is to develop an early indicator of potential cost growth. The basis of the cost growth (overrun or change in scope) must be pursued separately.

Cumulative expenditures as a percentage of the CBB at contract award were plotted against time for available shipbuilding construction contracts of the CG-47, FFG-7, and SSN-688 ship classes. Across the three ship classes, 445 data points were plotted. The costs shown in Figures 1, 2 & 3 are recorded by ship contract.

Figures 1, 2 & 3 exclude lead ship expenditures because detail design and nonrecurring costs create anomalies in expenditures compared to follow ships. As a result, only follow ships were analyzed.

As noted from Table 1, not all hulls within each ship class were represented. The DAES reports utilized at the time of research only had data for the hulls shown. Additional data sources are being pursued and will be incorporated in the future.

Simple linear regressions were performed on the data to determine the linear relationship between percent complete on a time basis and cumulative expenditures as a percentage of the CBB. The trend lines are shown in Figures 4, 5 & 6.

After analysis at the aggregate level, the data for each ship class was separated by shipyard and additional regressions were performed. Regression equations performed at the shipyard level had $R^2 > 0.90$ for each ship class. Due to specific shipyard analysis being business sensitive, the results could only be provided at an aggregate (total ship class) level as seen in Table 2.

The regression equations shown above depict straight line relationships between time and expenditure. When the data is presented graphically it is clear that the expenditure is not constant. The expenditure accelerates during the earlier stages of the contract, remains constant during the middle stage, and decelerates toward completion. The simple linear regression is most accurate in depicting expenditures during the middle stage (25% - 75% time interval) when the rate is constant, but does not accurately model the earlier or later stages. After examining other types of regressions, it was determined that the polynomial regressions more accurately reflect changing expenditures experienced during the earlier and later stages of the contract.

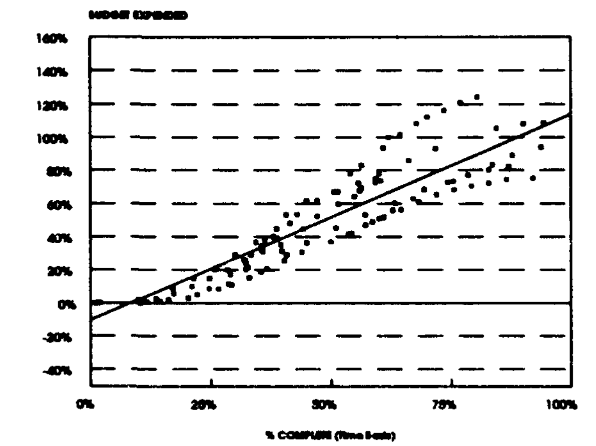


Figure 4 - CG-47 Class Simple Linear Regression

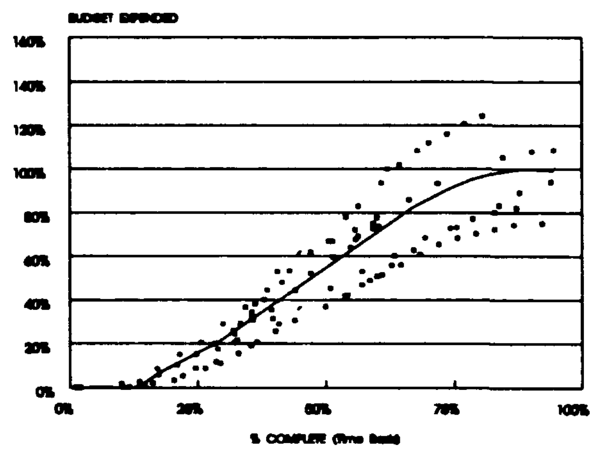


Figure 7 - CG-47 Polynomial Regression

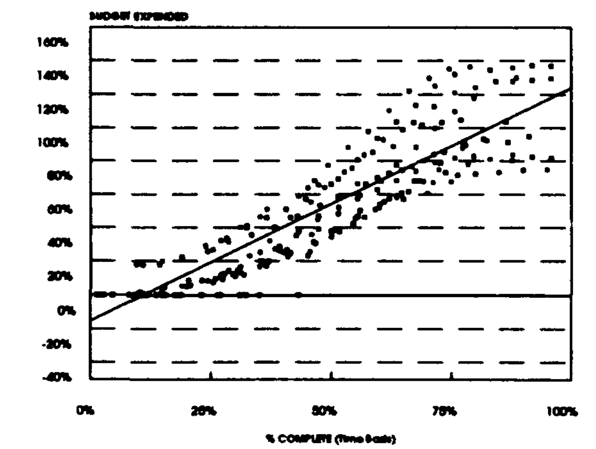


Figure 5 - FFG-7 Class Simple Linear Regression

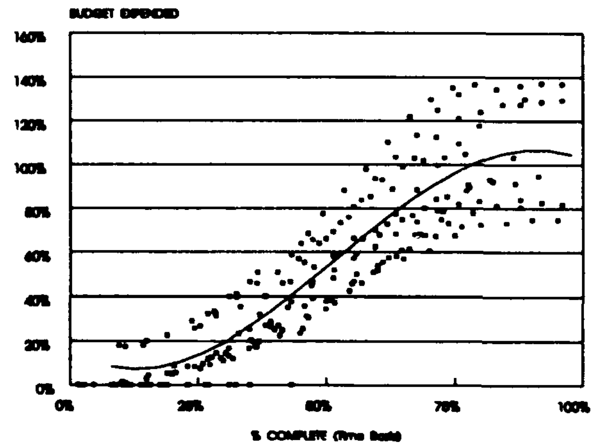


Figure 8 - FFG-7 Polynomial Regression

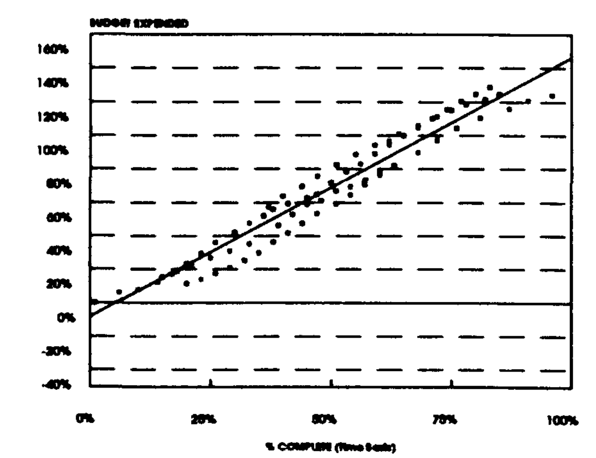


Figure 6 - SSN-688 Class Simple Linear Regression

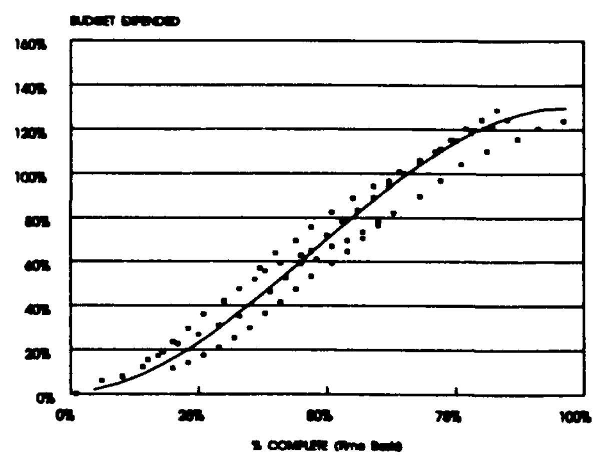


Figure 9 - SSN-688 Polynomial Regression

TABLE 2: Linear Regression				
Ship Class	Hull #'s	Regression Equations	R^2	# of Observations
CG-47	48,54-73	Y=1.21 X - 0.10	0.84	118
FFG-7	8-16,19-28,30,31,33,36-43	Y=1.38 X - 0.15	0.81	243
SSN-688	754-767,769,770,772	Y=1.49 X - 0.07	0.94	84
X = % complete on a time basis Y = % of the budget spent				

Utilizing STATGRAPHICS applied to the same data, numerous polynomial regressions were performed on the data to acquire the best curve fit. For the polynomial regressions, the data was modeled with constant, linear, squared, and cubic terms. The criteria for the best fit equation was the highest R^2. As shown in Table 3, the regression equations using cubic polynomial relationships more accurately delineate historical expenditure curves than the linear relationship previously developed.

Cumulative expenditures projected using the polynomial regression equations are depicted for the CG-47, FFG-7, and SSN-688 classes in Figures 7, 8 & 9.

Currently, a model exists which predicts ship construction expenditure rates. The model, known as the Naval Ship Expenditure Curve, is utilized by NAVSEA to forecast escalation cost for ship construction programs. Standard expenditure rates have been developed for labor and material costs. An analytical representation of this model is shown in Figure 10.

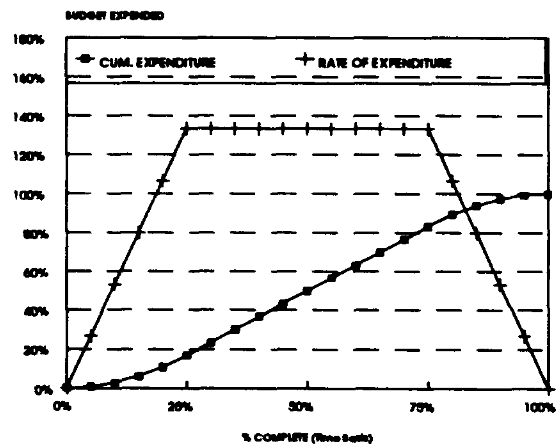


Figure 10 - Naval Ship Expenditure Curve

From Figure 10, the following three distinct construction periods are apparent:

Construction Period

- Build Up (0% - 25%)
- Peak and Stabilize (25% - 75%)
- Slow Down (75% - 100%)

Similar, distinct expenditure phases were observed in the return cost data for the CG-47, FFG-7, and SSN-688 classes. Figures 11, 12 & 13 compare the regression equations in Table 3 based on historical ship class expenditures to the Naval Ship Expenditure Curve.

It is clear that the trend for each of the curves is similar. Since expenditures are measured against the CBB at contract award, the regression equations reflect either a cost growth or savings due to overrun/underruns or baseline changes during the contract. This will result in expenditures exceeding or underrunning the CBB at completion. Other possible causes of cost deviation from the CBB may be contract type and acquisition strategy. Some contract types (e.g., FFP) entail more contractor risk. For these contracts, it is likely the CBB will be more conservative (larger) than a compa-

TABLE 3: Polynomial Regressions				
Ship Class	Hull #'s	Regression Equations	R^2	# of Observations
CG-47	48,54-73	$Y=3.21 X^2 - 2.24 X^3$	0.95	118
FFG-7	8-16,19-28,30,31,33,36-43	$Y = -0.49 X + 4.72 X^2 - 3.21 X^3$	0.93	243
SSN-688	754-767,769,770,772	$Y = 0.37 X + 3.17 X_2 - 2.26 X^3$	0.99	84
X = % complete on a time basis Y = % of the budget spent				

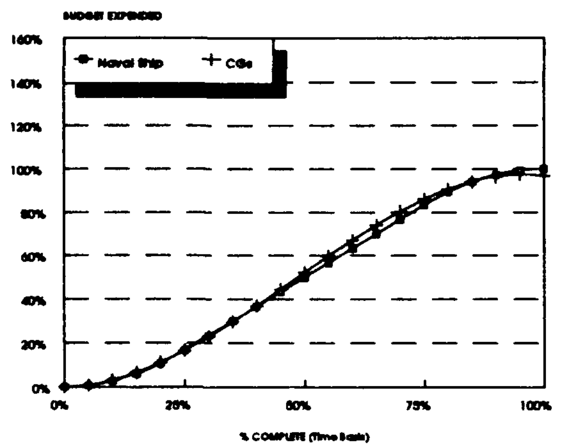


Figure 11
CG-47 Polynomial Regression vs Naval Ship Curve

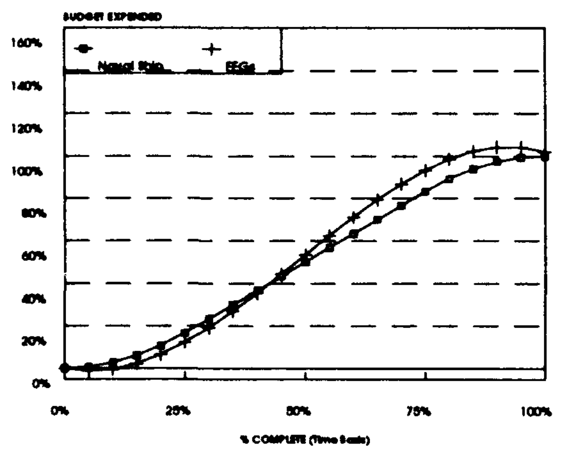


Figure 12
FFG-7 Polynomial Regression vs Naval Ship Curve

rable effort with less contractor risk. Similarly, the acquisition strategy will affect the CBB at contract award. The CBB for competitively awarded contracts is likely to be based on more aggressive cost assumptions than a sole source contract. These are possible considerations that should be reviewed in the future.

FINDINGS

The shape of the aggregate expenditure curves suggests that there are three distinct expenditure phases to each ship construction contract, and not necessarily a one-to-one ratio between the percent of the budget spent and percent complete on a time basis. Table 4 shows expenditures as a percentage of CBB at 40%, 60%, 80%, and 100% complete (time basis) for the CG-47, FFG-7, and SSN-688 classes relative to the Naval Ship Expenditure Curve.

The data suggests that excessive cumulative expenditures (i.e., higher than modeled projections) early in production may indicate cost growth at completion. At 40% complete, the CG and FFG cumulative expenditures are less than 40% of the CBB at contract award resulting in costs at completion which approximated the initial CBB. Conversely, SSN expenditures exceeded 40% of the CBB at 40% complete and exceeded the CBB by 27.8% at completion. A graphical representation can be seen in Figure 14.

The relationships shown above were derived at an aggregate level for each ship class. However, similar trends were observed for individual contracts within each ship class. High expenditure rates early in contract performance typically resulted in higher costs at completion relative to the CBB. Variations from the modeled expenditures observed in specific contracts at 40% complete continued throughout the contract.

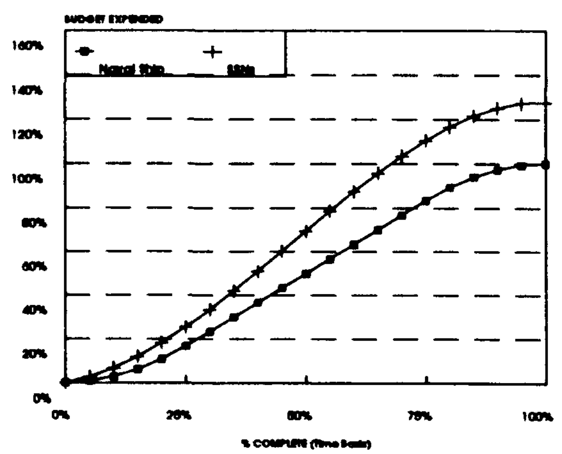


Figure 13
SSN-688 Polynomial Regression vs Naval Ship Curve

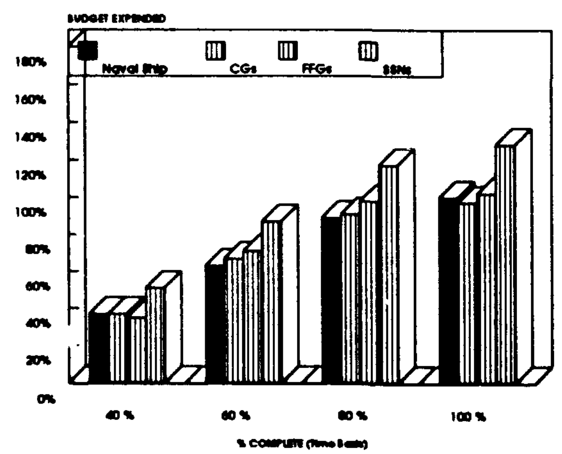


Figure 14 - Modeled Expenditures

TABLE 4: Modeled Expenditures					
Percent Time		40.0 %	60.0 %	80.0 %	100.0 %
CG-47	% Spent	37.0 %	67.1 %	90.6 %	96.7 %
FFG-7		35.3 %	71.2 %	98.5 %	102.1 %
SSN-688		51.0 %	87.4 %	116.6 %	127.8 %
Naval Ship		36.7 %	63.3 %	89.3 %	100.0 %

SUMMARY

The study confirmed that ship construction expenditures are consistent for specific ship classes and shipyards. Linear and polynomial regression equations were developed at the aggregate and shipyard specific level for the FFG-7, CG-47, and SSN-688 ship classes based on historical expenditure. Shipyard specific polynomial equations correspond most closely with historical expenditure profiles. The shipyard analysis suggests that for follow ship contracts there exists a characteristic expenditure curve that is unique for that particular shipyard. Significant deviation in actual expenditures compared to projected expenditures (based on polynomial regression analysis of historical data for follow ships of the same class) occurring as early as 40% into contract performance may indicate cost growth due to baseline changes or overrun.

RECOMMENDATIONS

The PM should consider expenditure rate analysis as a contract management tool to supplement contractor trend analysis techniques for ship construction contracts. Further investigation of the possible use of the expenditure equations as early indicators of potential cost growth should be performed. This analysis can be refined by utilizing data which is not only class specific, but in addition shipyard specific. Other possible considerations for future analysis are regressions with respect to contract type and acquisition strategy. Further study could also be performed to consider additional issues such as optimal construction periods for each ship class and the cost impact on compressing or lengthening of schedules.

BEST VALUE CONTRACTING

Thomas Demas
Assistant Project Manager
and
Michael Zacks
Project Engineer
Combat Support, Ocean Research
and Surveillance Project Office
(PMS 383)
Naval Sea Systems Command

May 1992

Approved For Public Release
Distribution Unlimited

The views expressed herein are the personal opinions of the authors and are not necessarily the official views of the Department of Defense nor the Department of the Navy.

ABSTRACT

The best value concept is based on making decisions on an offeror's technical competence, proven past performance, management capability, life-cycle costs, and product quality. The evaluation of these factors should be structured to ensure consideration is given to determine the overall benefit associated with the offered price. This paper advocates using the best value concept as the method for developing and rating proposal evaluation factors for procurement of new ships. It discusses methods for establishing evaluation factors, developing standards to evaluate the factors, associated documentation, and weighting and scoring the factors. The information for this paper was obtained from personal interviews, hands-on experience of developing and evaluating best value proposals, and documentation research. If properly executed, the best value concept will enable the Navy to improve ships while reducing operating costs.LIST OF FIGURES

LIST OF FIGURES

NOTATIONS/DEFINITIONS/ ABBREVIATIONS

ASN(RD&A) Assistant Secretary of Navy (Research, Development and Acquisition)
CICA Competition In Contracting Act
DAB Decision Acquisition Board
DoD Department of Defense
FAR Federal Acquisition Regulation
GAO General Accounting Office
NAVSEA Naval Sea Systems Command
RFP Request for Proposal
SSASource Selection Authority
SSP Source Selection Plan
WBS Work Breakdown Structure

INTRODUCTION

According to Dr. W. Edwards Deming, purchasing departments customarily operate on orders to seek the lowest-priced vendor: striking deals with the cheapest supplier is an accepted way of doing business in America. Awarding contracts that are the lowest in price but still technically acceptable has been a common practice within the Government. This approach frequently leads to poor quality goods and services. Deming strongly recommends ending the practice of awarding business mainly on price tag.

Dr. Deming's philosophy concerning quality is currently being applied within the Department of Defense (DoD). The Assistant Secretary of the Navy (Research, Development and Acquisition) has issued a memorandum for program executive officers emphasizing DoD's commitment to award contracts competitively on the basis of "best value" to the Government. Best value is defined as a method of awarding contracts for proposals that are most advantageous to the Government, considering other factors as well as price. "The current focus on best-value contracting is viewed by many on Capitol Hill, in the defense industry, and at DoD as simply the proper implementation of the 1984 Competition in Contracting Act (CICA) [1]."

"Since the introduction of CICA, the General Accounting Office (GAO) has handed down several decisions holding that the Government may not award without discussions with the offerors unless it is awarding the contract on basis of the lowest cost.

In one of these cases (Information Spectrum, Inc., B-233208, February 22, 1989), GAO found that the Navy stated in its solicitation that technical evaluation factors were *significantly more important than cost for purposes of* awarding the contract... GAO held that the Navy could not award to the company who had been judged more technically qualified, because there was another offeror who was within the technical range and had proposed a lower total cost [2]." This has been mistakenly interpreted by many within DoD to mean that contracts must be awarded based on lowest price, not lowest cost over the long term.

In an effort to clarify the interpretation of CICA, the House Armed Services Committee Report for the Defense Authorization Act for fiscal year 1991 indicates that Congress "has also attempted to make clear that an assessment of lowest overall cost is not limited to price and price-related factors. Cost encompasses not just price and price-related factors, but the outlay or expenditure the government will make over the life of a product. Cost also encompasses "technical" factors such as quality, design, technical capability, management capability, past performance, and cost discipline, etc., to the extent these factors can be translated into a monetary context, and offerors can be given a clear indication in the solicitation how those factors will be quantified [3]."

It was this new interpretation of CICA that introduced the new buzz words "best value," now being widely used throughout Government acquisition offices. However, if you were to ask what best value means, you would receive several different answer. (See Figure 1).

Figure 1 - Best Value Illustration

MILESTONES

The best value concept is applied differently during each "milestone" of a ship acquisition program. Milestones are those points during the acquisition process at which a Decision Acquisition Board (DAB) evaluates and approves the program. The process is normally divided into five phases, defined by Department of Defense Directive 5000.2, Defense Acquisition Management Policies and Procedures as: Milestone 0, Concept Study Approval; Milestone I, Concept Demonstration Approval; Milestone II, Development Approval; Milestone III, Production Approval; Milestone IV, Major Modification Approval. A brief explanation of each milestone is given below.

Milestone 0 occurs on approval of the program initiation and grants authorization to budget for a new program. At this juncture primary best value considerations are mission area analysis, affordability and life-cycle costs. The DAB's approval of the proposed mission allows the program manager to enter into the "Concept Exploration/Definition" phase.

Milestone I involves the decision to proceed into the "Concept Demonstration/Validation" phase. Here the primary best value considerations are program alternative trade-offs; performance, cost and schedule trade-offs; and affordability and life-cycle costs. This review establishes broad program cost, schedule, operational effectiveness and operational suitability goals. The principles of acquisition streamlining and design-to-cost are emphasized at this point.

During the Milestone II process, the DAB decides whether to proceed to "Full-Scale Development". The DAB review occurs before the release of the final Request for Proposals. Best value considerations are: affordability versus military value and operational suitability/effectiveness; risks versus benefits; development transition to production; industry surge/mobilization capacity; program stability; potential common-use solutions; and test results. Particular emphasis is placed on the requirements for the transition from development to production.

Milestone III marks the decision to proceed into the "Full-Rate Production and Initial Deployment" phase. The primary best value considerations are: results of operational evaluations; production or construction costs; affordability and life-cycle costs; production and deployment schedule; reliability; maintainability and integrated logistics support. Other considerations are producibility and procurement authorization.

Milestone IV, "Major Upgrade or System Replacement," normally occurs 5-10 years after initial deployment. Best value considerations are given to the original mission requirements, modifications that extend useful life, technology changes, and the disposition of displaced equipment.

This paper advocates the best value method for developing and rating proposal evaluation factors for ship development, Milestone II. The discussion will emphasize three evaluation factors, technical, management, and cost, that most commonly appear in solicitations.

EVALUATION FACTORS

According to the Federal Acquisition Regulation (FAR), a solicitation shall clearly state the evaluation factors, including price or cost and any significant subfactors, and their relative order or importance. The specific evaluation factors used will depend on the program. Every source selection shall include a cost evaluation factor.

Often, the most difficult task in preparing a solicitation is developing and defining the factors to be evaluated for award. The procedures for developing the evaluation factors are at the discretion of acquisition officials within the Government agency writing the proposal. The actual factors and any significant subfactors, however, must flow from the statement of work and must be tailored to the acquisition.

Evaluation factors may differ substantially among different kinds of acquisitions and, in the case of ship acquisitions, the factors may also differ according to the phases of the acquisition process. "It is important to make a distinction between evaluation factors/subfactors for hardware versus factors for service acquisitions. In service and/or research acquisitions, it is appropriate to use factors more closely akin to corporate performance capabilities. Serious thought should be given, and rationale developed, to be sure that the factors and subfactors discriminate among offerors [4]." Therefore, each factor must be defined clearly.

"The factors chosen as essential to the selection process can be broad in scope; however, they should be limited to aspects necessary to the success of the program [5]." Evaluation factors generally fall into the following functional disciplines: (1) technical, (2) management, and (3) cost. Figure 2 illustrates how evaluation factors and their relative order of importance may be shown within a solicitation.

In the past, these factors have been evaluated against a standard and measured as being either acceptable or unacceptable. In the context of a best value, the evaluators identify the strengths, weaknesses, deficiencies, or risks of each proposal. Rating points are assigned to those proposals exceeding the minimum requirements; points are reduced for weaknesses within proposals. Rating points can be shown as either a percentage or a series of ranges. The method of rating and scoring will be discussed in more detail later in this paper.

Technical Factor

Technical evaluation factors must not limit competition and should not overemphasize experience with the program itself, because this could make the factors unduly restrictive. Subfactors can have a significant impact on the source selection process. Therefore, it is essential to select subfactors that emphasize the essential requirements of the acquisition. The factors and subfactors should identify those items most critical to operational needs. This can be accomplished by preparing a project summary work breakdown structure (WBS) tailored to the program objectives, then developing factors to parallel the WBS.

SECTION M: EVALUATION FACTORS FOR AWARD

1. There are three factors, technical, management, and cost, to be evaluated by the Government in the Source Selection to determine the value to the Government.

2. The order of importance of these three factors are technical, management, and cost. These factors and their associated subfactors are as follows:

FACTOR 1: TECHNICAL

- a. Hull Structure
- b. Propulsion Plant
- c. Electric Plant
- d. Communications and Control
- e. Auxiliary Systems
- f. Outfit and Furnishings
- g. Integration/Engineering
- h. Ship Assembly

FACTOR 2: MANAGEMENT

- a. Business
  - 1. Project Management
  - 2. System Engineering
  - 3. Past Performance
  - 4. Data
  - 5. Manpower
  - 6. Training
- b. Schedules
  - 1. Master Schedule
  - 2. Procurement Schedule
  - 3. Production/Outfitting Schedule
  - 4. Design Schedule
  - 5. Tests and Trials Schedule
- c. Resources
  - 1. Peculiar Support Equipment
  - 2. Industrial Facilities

FACTOR 3: COST

- a. Cost/Price Data
- b. Materials
- c. Labor

FIGURE 2 - SAMPLE EVALUATION FACTORS FOR AWARD

Level 1	Level 2	Level 3
Ship System	Ship	Hull Structure Propulsion Plant Electric Plant Communications Auxiliary Systems Outfit and Furnishings Integration/Engineering Ship Construction
	Training	Equipment Services Facilities
	Systems Test and Evaluation	Developmental T&E Operational T&E T&E Support Test Facilities
	Data	Technical Publications Engineering Data Support Data Management Data Data Depository
	System/Project Management	Systems Engineering Project Management
	Industrial Facilities	Construction/Conversion and Expansion Maintenance

FIGURE 3
SHIP WORK BREAKDOWN STRUCTURE

A WBS is a product-oriented family tree composed of hardware, services, and data. A WBS displays and defines the product(s) to be developed or produced, relating the elements of work to each other and to the end product. Figure 3 illustrates a WBS for a Ship System.

The Ship System identified as Level 1 in Figure 3, is specified in the DoD programming budget system. Level 2 consists of the major elements such as ship, facilities, testing and evaluation systems, and data. Level 3 elements are subordinate to level 2 major elements. In preparing a WBS for a specific project, a selection of the level 2 and 3 elements from one or more of the summary WBS(s) for the appropriate category should be made. Additional information on WBS can be found in "Military Standard Work Breakdown Structures For Defense Material Items MIL-STD-881A".

STANDARDS

The next step in the process and the crux of the method, is to develop standards. "Standards provide a means for guiding the evaluators on how to rate/score factors and subfactors... A standard defines, describes, or otherwise provides a basis for considering a particular aspect of a factor [6]." In addition, standards help evaluators achieve consistent and impartial results. They may be either quantitative or qualitative. They are not, however, part of the solicitation.

In a best value contract, minimum points are assigned to the basis requirements for proposals as set forth in the solicitation. Additional rating points can be assigned to proposals that exceed minimum requirements in the scoring process. These points are translated into monetary value. The rating points can be shown either as a percentage or a series of ranges that surpass the minimum acceptable level.

In technical areas, standards can be quantified as a degree or percentage of the required threshold or stated goal to be obtained. For example, under the propulsion plant subfactor shown in Figure 2, the standard would emphasize quantitative parameters such as shaft horse power, plant size, generators, etc..

The propulsion system subfactor requirement of a solicitation might read as follows:

- The propulsion system shall be diesel electric and designed to function continuously during a 60 day at-sea deployment, without sustaining a system failure that cannot be corrected at sea or which degrades mission performance.
- The fuel economy shall be calculated on the basis of a standard thirty day mission, using the distribution of speed with time given in Figure 200-1. Performance that exceeds the standard requirements identified in Figure 200-1 will be given award preference.

The standard used to evaluate the factor could be expressed as follows:

- Does the Offeror provide a propulsion system capable of operating continuously during a 60 day deployment at sea?
- Does the propulsion system meet or exceed the standard fuel and speed requirements shown in Figure 200-1?

Many standards cannot be quantified easily because of the reiterative processes involved in ship design. In that case attributes stated in the form of questions can assist the evaluators. For example, under the ship assembly subfactor shown in Figure 2, the solicitation requirement might read:

- The offeror shall describe the engineering effort and material associated with the construction and test of the ship as a whole. This subfactor shall include as a minimum: temporary utilities, services, fixtures, special production tools, drydocking inspection, insurance launching, trials, and delivery.

The subfactor standards could be, for example,

- Does the offeror present an overall approach which indicates an understanding of the objectives, engineering effort, detail design, and construction of the ship?
- Does the offeror describe how the following materials (if required) relate to the construction approach: temporary utilities, services, fixtures, special production tools, drydocking inspection, insurance launching, trials, and delivery?

Each proposal's factors/subfactors will be rated against the requirements in the solicitation. The evaluators review the factors and subfactors within their technical field and highlight the strengths, weaknesses, deficiencies, or risks. Standards are provided to the evaluators to assist them in accomplishing this task.

Management Factor

The management factor must employ a different set of questions, due to the inherently diverse responsibilities of management. These include a broad range of affairs such as allocating resources; scheduling work; budgeting; communicating; and establishing organizational structure, goals, and the company's *vision*-culture. Given such diversity, it is again necessary to choose evaluation subfactors that focus on the specific acquisition.

When evaluating management in the context of best value, the emphasis should be placed on the organizational structure and past and present performance. The organization's performance should be evaluated to provide an indication of the company's culture. This is because culture is difficult to change, and a company's past performance is an indication of how well it will perform in the future. A clear understanding of these requirements should be conveyed to the offeror. This can be summarized by the evaluation factors stated in the solicitation.

For example, the project management subfactor should address the company's organization as well as its system for technical control. Thus the subfactor should encompass planning, directing, controlling, developing, and producing the entire ship, as well as consideration of logistics, maintenance support, facilities, personnel (manpower), testing, and activation of the ship. An example of how this might read within a solicitation is as follows:

- The offeror shall describe how the total construction program will be managed. This shall include planning, directing, controlling, developing and producing of the ship. An organizational chart shall be provided identifying key personnel, including their resumes. Additionally, offerors shall identify subcontractors and describe how they will interface with the shipyard organization and include data on logistics, maintenance support, facilities, personnel (manpower), testing, and activation of the ship.

As with the other subfactors, the management requirements are difficult to measure against quantifiable definitions or parameters. The standards expressed as a series of questions to used by the evaluator might be phrased as follows:

- Does the offeror describe the total construction program functions which include planning, directing, controlling, development, and production of the ship?
- Does the offeror provide an organization chart depicting the lines of communication and reporting structure within the company?
- Does the offeror identify subcontractors and describe how they will be integrated into the organization?
- Are resumes provided for key personnel?
- Does the offeror describe the logistics, maintenance support, facilities, personnel (manpower), testing, and activation of the ship to be accomplished?

The past performance subfactor should emphasize previous experience concerning systems and vessels of similar complexity. In addition, the subfactor should request that the offeror identify any problems that have arisen during execution of previous contracts. The offeror should discuss actions taken to resolve the problem(s) and describe how they would be applied to the proposed contract. This part of the solicitation might read as follows:

- The offeror shall demonstrate its application of systemic improvement management practices by showing how corrective actions taken or being taken have resolved past and present performance problems. The offeror should describe how its systemic improvement management approach would be employed if similar or related problems should arise in this program.

The standards for evaluation could be as follows:

- Does the offeror demonstrate the ability to isolate and trace past and present problems down to their source?
- Does the offeror clearly describe the procedures employed and actions taken to resolve the problem(s)?
- Does the offeror discuss how these procedures will be implemented in this program?

The following example illustrates the best value method

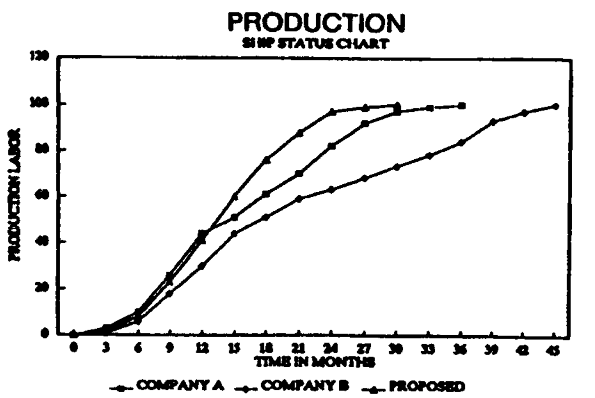


Figure 4 - Production Ship Status Charts

being applied for the past performance subfactor. Two companies are under contract to the government for similar products. They are both notified that equipment furnished by the government (GFE) will be delivered late. Upon being notified, Company "A" immediately commences a systematic work-around program, reducing the critical path while awaiting the late equipment. Company "B" continues working without change. This results in a work stoppage at a later date, affecting the program schedule. A comparison of the two companies' performance with the negotiated delivery date are illustrated in Figure 4.

In this example, Company "A" was responsive and took corrective action at the 12-month *period to minimize* schedule slippage. Suppose the contract came up for renewal and only one company could receive the new contract. Company "A" would receive a higher rating for past performance, thanks to the systemic improvements used to work around delayed material.

In addition to the previous methods identified in evaluating past performance in the context of best value, existing data should also be used to assure that the offeror can successfully accomplish the work. This can be accomplished by requesting comparative data from the offeror, e[illegible]ng Government data, information from procuring or co[illegible] administration offices, and by conducting on-site surveys to assess risk, if required.

Cost Factor

The last functional discipline to be considered is the cost factor, which requires the offeror to provide sufficient data for the Government to conduct price and cost analyses. Price and cost analyses are two techniques that complement one another. Because both are useful it is important to distinguish between the two.

Price analysis is used to determine whether a price is fair and reasonable. This analysis is most effective when there is procurement history and competition. This analysis evaluates the price without considering the offeror's estimated cost elements and profit. According the FAR, the contracting officer has the authority to use any or several of the following price analyses:

- comparison of proposed prices received in response to the solicitation.
- comparison of prior proposed prices with current proposed prices for the same or similar item.
- comparison of selected rough forms of measurement, such as dollars per pound or per horsepower, to highlight significant inconsistencies that might warrant additional inquiry.
- comparison with competitive published price lists, published market prices of commodities, and similar indexes.
- comparison of proposed prices with independent Government cost estimates.

To evaluate an offeror's cost data, each element of the estimated costs to perform the work must be examined. This involves analyzing cost accounting data furnished by the contractor. Additionally, it involves analyzing design features, materials, manufacturing processes, organization, and manning.

The cost analysis should verify the cost data, provide an understanding of how the offeror proposes to accomplish the *work, and identify* the offeror's cost in the proposal. According to the FAR, the contracting officer can use any of the following cost analyses to accomplish this:

- evaluate cost elements to verify cost or price data.
- evaluate the effect of the offeror's current practices on future costs; ensuring that inefficient or uneconomical practices are not projected into the future.
- compare individual elements cost proposed by the offeror for: (1) actual costs previously incurred; (2) previous cost estimates from the offeror or from other offerors for the same or similar items; (3) other cost estimates received in response to the Government's request; (4) independent Government cost estimates; and (5) forecasts or planned expenditures.
- check the offeror's cost submissions to ensure they are in accordance with the contract cost principles and procedures in Part 31 of the FAR.

In order to accomplish the cost and price analyses, the solicitation must request the offeror to submit a breakdown of each price (element) by ship WBS (Unit Price Analysis Summary). This includes a completed price breakdown forms; unit price analysis forms; shipyard overhead data;

cost groups; construction services; labor costs; project overhead; subcontract costs; and material costs. The offeror must also submit a copy of the company's financial data, financial information, and other cost data including accounting methods, material quantities, and unit prices and cost estimating relationships upon which the offer was made. The objective of the cost and price analyses is to determine if the price is fair and reasonable - so that the Government will receive the "best value". The Armed Services Procurement Manual for Contracting Pricing (ASPN No. 1) provides additional information regarding analysis and negotiation of contract prices.

The cost price team must coordinate its findings with the technical team. Current procedures ensure that cost/price information is not available to the technical/management (non-price) evaluation team, to avoid influencing its findings. These procedures are a barrier to best value evaluations, which must be done concurrently by both the cost/price team and non-price team with free flow of information between them. Unless deficiencies found in the technical evaluation are made known to the cost/price team, the validity of the cost evaluation will be adversely affected.

DOCUMENTATION

The technical, management, and cost factors and their relevant subfactors are included in: (1) Attachment 1 to Section L of the RFP; (2) Section M of the RFP; and (3) Source Selection Plan.

Attachment I to Section L provides instructions and conditions, and informs the offeror on how to organize the proposal (number of volumes and page limits). This section also describes the type of contract, where copies of documents can be obtained and how proprietary information should be marked.

Section M informs the offerors how the Government intends to evaluate the proposals. The relative order of importance of the factors is given in this section. Since best value implies that quality is more important than cost, the cost factor must never be so overriding that the non-price factors (i.e. technical and management) are less significant. The overall importance placed on the cost factor should never be more than or equal to the non-price factors combined. This leads to problems, however, since the Navy Acquisition Procedures Supplement (NAVSO P-3670 stock number: 0518LP2049400) states that the cost factor should carry a weight of not less than 40% unless thoroughly justified. The best solution at present is to try to keep the cost factor between 40-49 percent of the total.

The source selection plan (SSP) shall include, as a minimum, the following: a description of the agency's organization structure; a summary of its acquisition strategy; a statement of the agency's proposed evaluation factors and their relative importance; evaluation methodology; and a schedule of milestones. The evaluation methodology describes the evaluation process, including the techniques to be used, the standards, and methods of rating, weighting, and scoring the factors and their relevant subfactors.

Rating

"Rating methods include quantitative (numerical), semi-quantitative (red-yellow-green criteria, pass-fail criteria), qualitative (narrative), or a combination of any of the preceding. Caution should be used in selecting the rating methods."[7] Each method is discussed below with as it applies to best value.

The objective of the numerical rating method is to provide a means of discriminating among a number of competing proposals by rating them against the various subfactors. It employs a pre-established scale for each specific subfactor. A specific set of ranges is used by the evaluators for factors and subfactors susceptible to this method. The rating ranges should permit the evaluators to make desired distinctions while keeping the mathematics as simple as possible. Typical numerical ratings ranges are 0 to 10 in increments of one. Other ranges or combinations may be used to suit the acquisition program. The following numerical ratings are an example of quantitative technical and management factors for a best value ship acquisition:

<u>Numerical Rating</u>

Outstanding	10, 9
Excellent	8, 7
Good	6, 5
Acceptable	4, 3
Marginal	2, 1
Unsatisfactory	0

The semi-quantitative (red-yellow-green criteria, pass-fail criteria) rating method is used to evaluate a proposal's ability to meet minimum requirements. Color criteria consist of red (poor), yellow (questionable), and green (satisfactory). Pass-fail criteria and color criteria help identify hidden costs associated with buying low quality products. The semi-quantitative rating method is not suitable for best value type contracts, but is more appropriate for technically acceptable, low-cost contracts. For example, typical pass-fail criteria used in ship acquisition programs for quantitative technical and management factors are as follows:

- <u>Pass</u> - The Offeror's proposal conforms to the solicitation and any deficiencies in the proposal are considered minor.
- <u>Fail</u> - The Offeror's proposal does not conform to the solicitation requirements, omits information needed to determine whether the proposal meets solicitation requirements, or contains information

that is erroneous or contradictory to the requirements of the proposal and cannot be made acceptable without significantly changing the proposal.

Narrative ratings utilize adjectives to rate subfactors. Each adjective provides a means of comparing a proposal to an established standard. The narrative evaluation should highlight strengths, weaknesses, deficiencies, and risks associated with each factor. The adjectives used should cover the complete rating spread, from the lowest (unacceptable) to the highest possible rating (outstanding). Each adjective should be fully defined. The following adjective ratings are typical of those used in best value ship acquisition programs for qualitative technical and management factors:

- Outstanding - the proposal factor exceeds the requirements of the RFP and provides strong assurance that the offeror will successfully accomplish the work. The offeror has demonstrated an understanding of the RFP's requirement, which when implemented should accomplish the task in an effective and economical manner. A rating of 'outstanding' means this proposal contains exceptional strengths, and features or innovations which would enhance the shipbuilding program or otherwise be of benefit to the Navy. There are no evident weaknesses of any nature present.

- Excellent - the proposal factor meets the requirements of the RFP. The offeror is responsive and provides assurance the offeror will successfully accomplish the work. Any weakness is of a minor nature which poses little risk of adversely affecting the offeror's performance. A rating of 'excellent' is used when there are no significant exceptional strengths, features or innovations which would enhance the shipbuilding program or otherwise be of benefit to the Navy.

- Good - the proposal factor is adequately responsive with minor deficiencies but no major deficiencies noted. The proposal factor meets the requirements of the solicitation. In terms of the proposal factor, the offeror is likely to satisfactorily complete the assigned tasks despite weaknesses in the proposal. The level of risk is low to moderate.

- Marginal - the proposal meets the intent of the requirements of the RFP but presents a shallow or in sufficiently detailed approach. The proposal contains weaknesses in several areas that are not offset by strengths in other areas. In terms of the specific factor, the offeror might complete the assigned tasks but the risk is moderate to high. The combination of major and minor weaknesses makes it doubtful the offeror will perform as proposed.

- Unacceptable - the proposal does not meet the requirements of the RFP or does not address the specific factor. The offeror's interpretation of the government's requirements is incomplete, vague, incomprehensible, or incorrect. The assignment of a rating of 'unacceptable' indicates that mandatory corrective action would be required to prevent major weaknesses from affecting the overall program. There are no significant major or minor strengths, and many significant major and minor weaknesses.

A method combining the numerical rating approach with the narrative rating approach is considered best when both quantitative and qualitative technical and management factors are present in a best value contract. This method requires the evaluator to first provide a narrative description of each proposal, subfactor by subfactor. The use of work sheets will allow evaluators to describe the attributes and deficiencies of the proposal. "Evaluators should complete narrative descriptions prior to assigning a rating to a factor/subfactor so that the rating will reflect the evaluator's findings, rather than having the narrative justify the assigned rating [8]."

Weighting

Weighting numerical and adjective ratings makes it easy to see the relative value of each factor. The Source Selection Authority (SSA) assigns an overall weight to each factor. There are two separate and *distinct weights assigned*. One weight reflects the relationship of each factor to the total evaluation and is normally shown as a percentage. The other weight describes the relationship of each non-price subfactor to its overall factor and is normally shown as points. Weightings for either numerical or adjective ratings are developed and assigned by the SSA, as part of their review and approval of the SSP. Section M of the solicitation indicates to the offerors' the relative importance of each factor but does not reveal the specific weights assigned.

To illustrate the interplay of weights and numerical ratings for non-price factors, assume that the non-price factors (i.e. technical & management) are worth 60%, and the cost factor is worth 40% of the total evaluation. Within the non-price factors, the SSA has determined that the technical factor should be worth 70 points and management factor worth 30 points. For this example, three offeror's non-price factors are assigned points, totaling 100, and distributed as shown in Figure 5. The technical evaluation team has assigned numerical ratings to the non-price factors based on ranges from 0 (unsatisfactory) to 10 (outstanding).

As this example shows, both Offeror A & B obtained similar ratings of 5 & 10 respectively. However, Offeror A's weighted score was 200 points higher than Offeror B's score because they obtained a rating of 10 in technical which was weighted more than the management factor. The impor-

Offeror	Factor	Weight		Rating	Score
A	Technical	70	X	10	700
	Management	30	X	5	150
	Business (10)				
	Schedule (10)				
	Resources(10)				
	Total	100			850
B	Technical	70	X	5	350
	Management	30	X	10	300
	Business (10)				
	Schedule (10)				
	Resources(10)				
	Total	100			650
C	Technical	70	X	4	280
	Management	30	X	5	150
	Business (10)				
	Schedule (10)				
	Resources(10)				
	Total	100			430

FIGURE 5
INTERPLAY OF WEIGHTS WITH NUMERICAL RATINGS

tance placed on the technical factor in this example is not typical for a ship acquisition solicitation, but is used to emphasize the importance weighting can have on an evaluation.

Offeror	Factor	Weight	Factor Rating
A	Technical	70	Outstanding
	Management	30	Good
	Business (10)		
	Schedule (10)		
	Resources(10)		
	Final Rating		EXCELLENT
B	Technical	70	Acceptable
	Management	30	Outstanding
	Business (10)		
	Schedule (10)		
	Resources(10)		
	Final Rating		GOOD
C	Technical	70	Acceptable
	Management	30	Good
	Business (10)		
	Schedule (10)		
	Resources(10)		
	Final rating		ACCEPTABLE

FIGURE 6
INTERPLAY OF WEIGHTS WITH ADJECTIVE RATINGS

The interplay of weights and adjective ratings for non-price factors is not easy to visualize. The final overall adjective rating is obtained through reasoned judgement, based upon an optimum balance of risk, so that the relative acceptability of each is readily apparent. To illustrate the interplay of weights and adjective ratings, assume again that the same non-price factors shown above are rated using adjective ratings. The technical factor weight is 70 points and the management weight is 30 points, as shown in Figure 6.

The weight is not used as a multiplier, but rather to indicate the relative importance of each factor. No cook book answers or solutions are available for guidance on how one might assign the final rating. The SSA must use judgement and assign an overall adjective rating based upon strengths, deficiencies, weaknesses and risks of the offerors proposal. As evident, weighting of adjective ratings gives the SSA much more flexibility in determining the offerors overall rating than if numerical ratings were used, and therefore are preferred.

Technical, management, and cost factors can be scored by any rational and logical method, so long as they meet the tests of reasonableness and impartiality. It is as difficult to translate cost data into a scoreable numerical representation as it is to translate technical and management data into cost. Since best value implies the Government is willing to pay a premium in the technical category, one must calculate the monetary value of the technical worth. One method of calculating the monetary value of the technical worth is provided in the following example.

The SSA decides to consider only those offerors found acceptable in technical/management factors (otherwise know as the competitive range). The numerical score for an acceptable to outstanding rating fall between 3 and 10 as discussed earlier in this paper. As our previous examples shows, all three offerors were found acceptable and should be scored. If the technical and management factors combined are worth 60% and the cost factor is worth 40% of the total evaluation the monetary value of each offerors proposal can now be calculated. Figure 7 lists each offeror and its evaluated cost and technical score.

Offerors	Governments Evaluated Cost and Proposed Fee	Weighted Technical Score
A	$6,846,970	850
B	$5,550,706	650
C	$4,799,445	430
Difference between High/Low score:		420

FIGURE 7
SCORING BEST VALUE CONTRACTS

The monetary value which the Government is willing to pay is calculated by:

(1)Dividing the weight for the non-price factors (60% or 60), by the total available numerical scores in the competitive range (3 - 10 = 7 points) as shown below:

60 percent / 7 points = 8.57 percent/points

(2) Multiply the solution (8.57 percent/points) by the difference between lowest weighted technically acceptable score and the highest weighted technical score (850 - 430 = 420 points) and dividing by 100, as shown below:

8.57 percent/points X 420 points / 100 = 35.994 percent or (1.35994)

(3) Multiply this percentage (1.35994) by the lowest evaluated technically acceptable cost & fee (i.e. Offeror C = 4,799,445) as shown below:

$4,799,455 X 1.35994 = $6,526,971

This is the calculated monetary value the government is willing to pay. An award would than be made to offeror B, because B's evaluated cost is lower than the amount the Government is willing to pay. Although offerors A had the highest technical score, they exceeded the amount the government was willing to pay and therefore were out of the running.

If adjective ratings are used, they must be converted to a numerical score, and the same procedures identified above would applied. It is essential that the evaluation team take advantage of the full range of adjective ratings so that the variations among proposals are readily apparent.

CONCLUSION

In conclusion, when evaluating proposals according to the concept of best value, the method that combines a numerical rating approach with a narrative rating approach is considered best when both quantitative and qualitative technical and management factors are present.

The best value concept is applied differently to each ship acquisition program. Various methods are used to inform the shipbuilders of the Government's requirements. If the Navy uses a specification to identify standard ship requirements, the technical factor would be emphasized during the evaluation process.

On the other hand, if the offeror is to prepare the ship specification, as required when using a Circular of Requirements (COR), the management factor would be emphasized during the evaluation process. This is because the Government is more concerned with how the shipbuilder will manage and control the program versus the ship characteristics provided the shipbuilder's specifications meet the design parameters established by the requirements.

The cost/price team and technical/management team must have a free flow of information between them to fully implement the best value concept into ship acquisition programs, otherwise the validity of the cost evaluation will be adversely affected.

The weight placed on the cost factor should never be more than or equal to the combined non-price factors. If the cost equal or exceeds the combined non-price factors weight, the final decision to award the contract would be determined by the offeror submitting a technically acceptable low cost proposal.

SUMMARY

Best value can be summarized as a means of achieving the greatest benefit to the government by considering such factors as price, quality, design, performance, management and technical capabilities, and life-cycle costs associated with the product. This paper discussed methods for establishing evaluation factors which are the basis for determining benefits, evaluating the benefits with standards, and determining the monetary value of the benefits by weighting their importance and scoring their worth. Evaluation factors are presented in three generally accepted functional disciplines; technical, management, and cost. Sub-tier factors for these functional disciplines are developed through the project summary work breakdown structure (WBS), tailored to each specific acquisition. Quantitative and qualitative standards are developed for each subfactor assisting the evaluator in making judgements as to their relative worth. If properly executed, the best value concept will enable the Navy to improve ships while reducing operating costs.

ACKNOWLEDGEMENTS

Preparation of this article was supported in part by association of Scientists and Engineers of the Naval Sea Systems Command.

We gratefully acknowledge Janice Menker (Professor, Defense Systems Management College), Mr. V. S. Carberry (Executive Director for Contracts Management, Naval Air Systems Command) and Jim Ripley (NAVSEA Quality Engineering) for providing valuable information used in the development of this paper.

We appreciate the following individuals for their assistance in reviewing this paper: Susan Zacks (Writer/Editor, Bureau of National Affairs, Inc), Robert M. Mallard (Advanced Marine Enterprise, Inc.), Harriet G. Berlin (Independent Manuscript Development Consulting and Editing), Jesse

Atkins (Deputy Program Manager, PMS383), Ninette Sadusky (Project Engineer, PMS383A2), and Julie MaGinnis (Presearch Inc.).

ENDNOTES

[1] Terino, J. (1991). Buy-ins are out best-value contracting is in. Journal of the American Defense Preparedness Association, National Defense, LXXVI(470), 20-23.

[2] The Bureau of National Affairs, Inc. (1990). Excerpts from house armed services committee report to accompany HR 4739, fiscal 1991 defense authorization act. Federal Contract Report, 54, 212-214.

[3] The Bureau of National Affairs, Inc. (1990). Excerpts from armed services committee report to accompany HR 4739, fiscal 1991 defense authorization act. Federal Contract Report, 54, 212-214.

[4] SEA 90 (1989). NAVSEA Source Selection Guide. Washington, DC: Department of the Navy, Naval Sea Systems Command, p. 4-5.

[5] SEA 90 (1989). NAVSEA Source Selection Guide. Washington, DC: Department of the Navy, Naval Sea Systems Command, p. 4-4.

[6] SEA 90 (1989). NAVSEA Source Selection Guide. Washington, DC: Department of the Navy, Naval Sea Systems Command, p. 4-7.

[7] SEA 90 (1989). NAVSEA Source Selection Guide. Washington, DC: Department of the Navy, Naval Sea Systems Command. p. 4-17.

[8] SEA 90 (1989). NAVSEA Source Selection Guide. Washington, DC: Department of the Navy, Naval Sea Systems Command. p. 4-18.

REFERENCES

Armed Service Pricing Manual (ASPM No. 1), Department of Defense, 1989.

by Mary Walton, "THE DEMING MANAGEMENT METHOD", The Putnam Publishing Company, 200 Madison Avenue, New York, NY 10016, 1986.

Bureau of National Affairs, Inc., Federal Contract Report, Washington, D.C. vol 54, pg. 212-216.

Department of Defense Directive 5000.2, Acquisition Management Policies and Procedures, dtd 23 February 1991.

Federal Acquisition Regulation, Department of Defense, October 1990 edition, with Federal Acquisition Circular 90-9, dtd 27 December 1991 (effective 25 February 1992).

Journal of the American Defense Preparedness Association , National Defense, Sept 91, Vol. LXXVI, number 470.

Military Standard MIL-STD-881A, Work Breakdown Structure for material Items, dtd April 1975.

Naval Sea Systems Command Source Selection Guide, dtd 31 March 1989.

Navy Acquisition Procedures Supplement, Department of the Navy Office of the Assistant Secretary (Shipbuilding and Logistics), april 1989 edition.

Webster's New Collegiate Dictionary, G. & C. Merriam Company, Springfield, MA, 1979.

Model To Analysis Protocols MAPping The Future

Thomas P. Morgan
Naval Architect
Computer Aided Engineering Division
(SEA 507)
Naval Sea Systems Command

May 1992

Approved for Public Release
Distribution Unlimited

The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense nor the Department of the Navy

Abstract

The Model to Analysis Protocols (MAPs) Project was initiated to link "Product Model" (both non-graphic and graphic) information to analysis programs in a consistent manner, and to prepare for the implementation of the CAD 2 systems. There are over 50 distinct analysis areas in NAVSEA (such as hydrodynamic analysis, noise analysis, electromagnetic analysis, etc.). The MAPs project is looking at the specific data elements needed to support each analysis area, and the relationships between data elements. By using Computer-Aided Software Engineering (CASE) tools, the data elements are modeled and can be translated into a relational database. When modeling each area, the common data elements between analysis areas are identified. These elements can be created on a distributed database implemented on CAD 2 workstations throughout NAVSEA. This distributed database will eliminate redundant data and allow concurrent engineering in the design process to become a reality.

Definitions

Analysis An examination of a complex (i.e. system), its elements, and their relations [2]. Analysis is performed on a model.

CAD 2 Computer Aided Design 2, a requirements contract for CAD systems (hardware and software) awarded to Intergraph in April 1991.

CAE Computer Aided Engineering.

CAEDOS Computer Aided Engineering and Documentation System, a.k.a. CAD 1, a contract for CAD systems awarded to Computervision in 1984.

CASDAC Computer-Aided Ship Design and Construction, the precursor to the CSD Project.

CASE Computer Aided Software Engineering.

Computer System Consists of both the computer hardware and the software necessary for operation

CSD Computer Supported Design; also the CSD Project, an ongoing project to develop and integrate computer tools to support ship design, managed by SEA 507.

IGES Initial Graphics Exchange Standard.

Model A type or design of a product [1]. A Product Model is the graphic and non-graphical data necessary to build the product.

Modeler Either a computer program that creates data for later analysis or a person who uses such a program.

NIAM Nijssen's Information Analysis Method.

NIDDESC Navy-Industry Digital Data Exchange Standards Committee

PDES Product Data Exchange Standard (or more recently, Product Data Exchange using STEP, STEP standing for Standard for the Exchange of Product Model Data)

Protocol A set of conventions governing the treatment and especially the formatting of data in an electronic communications system [3].

INTRODUCTION

The Model to Analysis Protocols (MAPs) project was initiated to help integrate analysis and modeling tools. A standard protocol between the analysis tool and the modeler is defined by way of an information model. This protocol requires the modeler to define data needed by the analysis program (model requirements) and defines the format and access methods of the data. Currently there are several modeling programs supporting several hundred analysis programs at NAVSEA. How did this plethora of model and analysis tools come about?

HISTORY

Computing has been improving at the annual rate of some 25 percent for at least the past two decades [4]. Hardware costs have been dropping while computing power has increased.

However, software functionality has increased at a slower pace, and the cost and complexity of software has increased considerably. In order to develop and analyze the many data elements that comprise a ship design, computers are a necessity [5].

Islands of Automation

As computer technology matured, NAVSEA engineers were quick to automate the analysis of their designs. A formal project, CASDAC (and later superseded by the CSD Project) was formed to aid the development of analysis programs. Except in a few areas, each analysis area has grown up separately, with little data exchange or common analysis capability used. This has resulted in islands of automation.

As analysis programs became more complex, the data input volume and complexity increased. Specialized modeling programs were developed to provide input for these analysis programs. One example of a specialized modeler/analysis program is the Topside Design Model (TDM), a computer system to aid in the development of a ship topside. In order to easily perform the analysis, simple 3-D prismatic shapes (variants of cubes and cylinders) are used to model the topside. Once defined, several types of topside analysis can be performed - weapon/radar line of site, radar range, and many others. The analysis modules of TDM are tied to these data elements - the addition of a sloped side prism such as is needed for a DDG 51 type superstructure would require a major rewrite of TDM. Defining the topside model using TDM is time consuming and error prone. Some of TDM's capabilities have been superseded by the Blockage Assessment Model (BAM), which uses flat plates to model the ship, overcoming the sloped side limitation of TDM.

Other examples of modeler/analysis programs used for ship design include the General Arrangement Design System (GADS), The Hull Form Design System (HFDS) and specialized modeler/analysis programs for Radar Cross Section (RCS) analysis. Each of these systems requires or defines information about the ship design.

There are over 50 design disciplines at NAVSEA (e.g. Hull Form, Stability, Arrangements, Structures, Electromagnetic Engineering, RMA, Noise, HVAC, etc.) with several supporting analysis programs for each discipline. Each analysis may require information from several sources. For example, a radar range analysis will need the radar height above the waterline and frequency, whereas a survivability analysis would require information on hull geometry, materials, structure, arrangements and systems. This is shown graphically in Figure 1.

In addition, the type of analysis performed can dictate the form of the model. For example, hull resistance analysis requires a smooth surface representation of the hull whereas structural analysis requires a FEM (Finite Element Model) representation of the hull. These different 'levels of definition' must be supported by MAPs and the CAD 2 system.

Most analysis programs are not only tied to a specific model

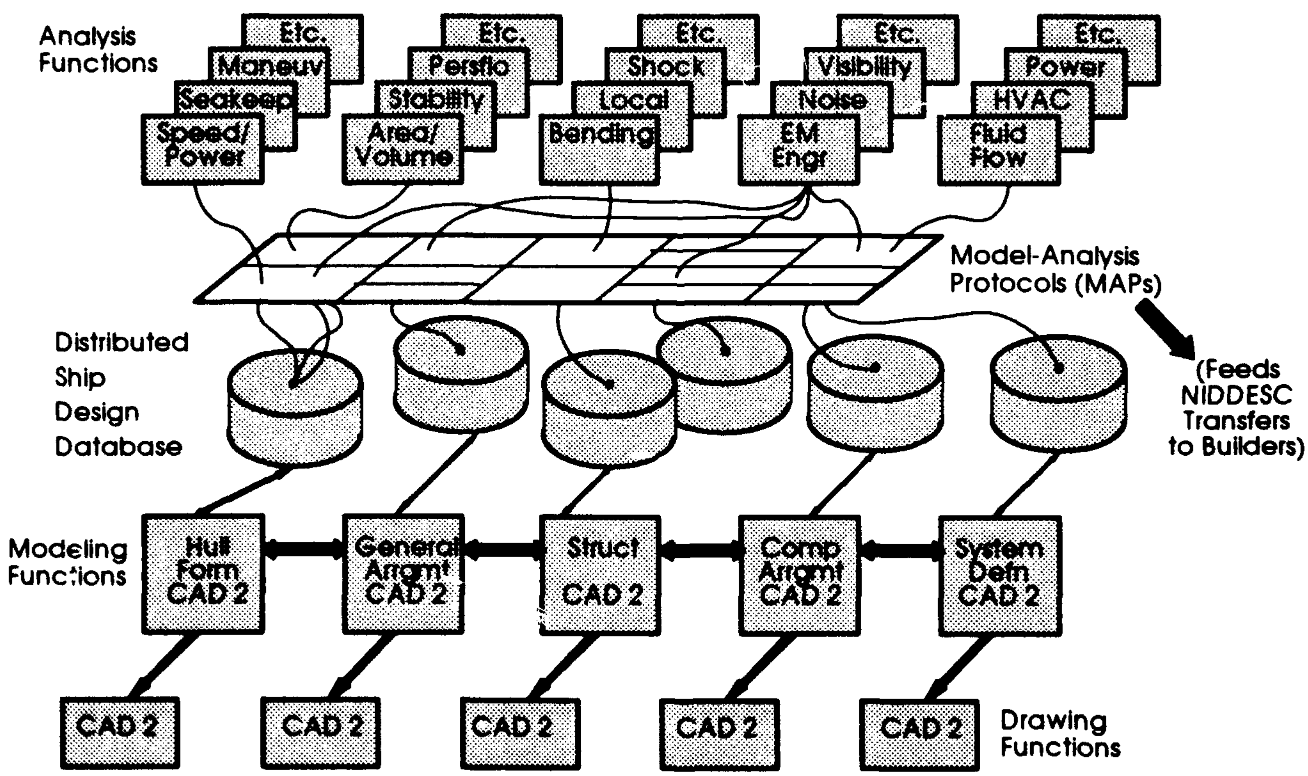


FIGURE 1 - Design Digital Data Flow

format and definition, but most modeler and analysis programs are also tied to specific computer architecture. Although most of the analysis programs at NAVSEA are written in FORTRAN, many use machine specific instructions and specialized graphic routines for the 3-D geometry. This makes the analysis programs difficult to port (transfer or rewrite) to different computer architectures, such as the CAD 2 system. NAVSEA 507 has produced a specification for software design that would make it easier to develop and port analysis software [7]. Unfortunately, many analysis programs are developed without this specification.

These islands of automation still exist today. It is hoped that by defining the data content and format and providing a common modeler by way of the CAD 2 system will help consolidate the product model data.

Linking of Modeling Programs

It became evident that the modeling programs were defining similar data, only in a different format. This was an obvious duplication of effort. Also, configuration control of the ship design was difficult to maintain, as a change to the design had to be duplicated in each model. The majority of the time spent in design was modeling the data for the analysis, with the actual running of the analysis taking a fraction of the total time. Transferring data between modeling programs would reduce the duplication of effort and help maintain configuration control. Bridges between these 'islands of automation' were implemented by way of translators. Translators between modeling programs used both standard formats and neutral ad hoc formats, described further below.

Standard data format translators

One method of data transfer between modeling programs is by a formal standard such as IGES (Initial Graphics Exchange Standard) or by a de-facto standard such as DXF (digital exchange file) popularized by the makers of AUTOCAD. The SEAWOLF project used IGES successfully to transfer data between Newport News and General Dynamics Electric Boat Division [7]. However, the data was primarily graphical information. This type of information has little analysis usefulness without adding additional non-graphic information. In order to pass non-graphic information, IGES has been extended for some special analysis needs [8]. IGES data files tend to be large, sometimes 5 to 20 times the size of the native (original) data format. Translators based on IGES are difficult to implement due to the number of entities supported and ambiguities in the IGES specification. Also, many data types are not supported in the current revision of IGES. This results in a loss of some information when data is translated from one computer system to another.

To get around IGES' limitations, many translator implementors have resorted to 'flavoring' IGES, that is, using certain IGES entities to define special purpose elements. An example of 'flavored' IGES translation between NAVSEA modeling programs is the GADS to BAM link, and a GADS to CV link preserving GADS compartment grouping and naming. IGES flavoring is inherently non-portable, as a third party translator would have no idea what the special purpose element meant.

The Product Data Exchange Standard, or PDES, is under development, and is designed to transfer non-graphic as well as graphic information. NIDDESC is leading the development of a PDES specification for ship product model data. However, translators implementing PDES are years away from becoming a reality.

Neutral files

A neutral file in the computer sense is an ad hoc data format that contains information to be transferred usually between two differing data formats. Usually the file is formatted as an ASCII flat file, in which the data elements are represented by records (or lines) and fields in a text file. The advantages are that the file is easily readable and editable by any text editor, making testing easier.

The neutral file can contain both graphical and non-graphical information, as it is tailored to the application. The files are usually much smaller than a standard format representation. An example of a large scale neutral file application is the data transfer of DDG 51 product model information between Bath and Ingalls. In this case, part instance information (the location and orientation of a part) was transferred between the two companies. The actual part was not transferred - it was assumed that an equal part existed on both companies' computer systems. A simple cross reference was used to match parts. This greatly reduced the amount of data to be transferred [9].

Many links between the NAVSEA analysis 'islands of automation' have been created over the years using neutral files. Some of them include:

- Geometry and payload data transfer from ASSET (Advanced Surface Ship Evaluation Tool) to TDM
- System configuration from Computervision to TIGER (an analysis program that does reliability, maintainability and availability (RMA) analysis program)

Disadvantages

In almost all cases, the transfers were one-way. In many cases the translators were quickly put together to support a certain design project, and then left unsupported. The modeling programs themselves were evolving and as their internal data formats changed, the translators would also need to be updated. By their very nature, an ad hoc neutral file is special purpose, and using it's format to transfer data to another modeler is impractical. Also, the neutral file may lack a formal definition, which makes writing a new translator for another modeler difficult.

Other disadvantages of using either standard or neutral data exchange formats are:

- The translators are tied to individual revisions of data format. If the internal data formats changed in either modeler or the translator file format changed, the translators would have to be updated.
- The transfer data file must be tracked and configuration controlled.
- The translators take time to operate. The transfer process adds a time lag to the design process.

The translator creates a dependency between the two modeling programs. If an engineer wanted to analyze a different configuration, he would have to ask the upstream engineer to model the new configuration and then transfer it. This reduces the number of design iterations possible. For this reason the downstream engineer usually retains his capability to do his own modeling, passing changes back manually.

Previous / Current Attempts at Data Consolidation

One obvious solution would be to integrate all analysis programs modeling needs into one modeler, preferably on one computer system. This has been attempted in the past, and has been successfully implemented for a narrow set of analysis programs. For example, the Electromagnetic Engineering Program specifies a common modeler with links to several analysis programs and inputs from other data sources [10].

A large scale project called the Integrated Data Base (IDB) was attempted in the early 1980's [11]. The IDB's scope included all of the analysis performed during ship design. Many analysis data elements were defined in the project, and sample databases were created. However, a common modeler to manipulate the data did not exist and the database technology at the time was not capable of supporting the complexity of the data. Also, the techniques of defining the data elements were not well developed. As a result, most of the effort to define the data elements and their relationships were lost. However, many of the lessons learned were used as requirements in the CAD 2 specification.

CAD 2 Solution?

The early CAD 2 specification was certainly meant to be all things to all people. However, many of the analysis requirements were not commercially available. The specification was trimmed down to those model and analysis requirements that were currently available. Nevertheless, the end result was a specification that challenged the computer industry and resulted in a useful computer system.

The Intergraph systems procured under the CAD 2 contract have very powerful graphical modeling programs capable of modeling the complex solids and surfaces of a ship. The systems can be equipped with several integrated analysis programs in the areas of structural, HVAC, piping, and electrical analysis. The systems are highly tailorable, allowing easy integration of custom analysis programs and modeling techniques. The systems also come with a distributed relational database capability with links from graphical elements to the relational database.

However, the analysis requirements cut from the original specification are still required to design a ship. No specific 'ship design software' is included on the CAD 2 contract. It is estimated that less than 25 percent of the analysis capability needed to create a ship design is currently integrated on the CAD 2 system.

Objective

The initial objective of the MAPs project was threefold:

1. Provide a standard procedure for integrating model data with analysis programs.
2. Allow for new analysis programs and modeling programs (i.e. CAD 2) to be easily integrated into the computer system.
3. Provide a standard format for model information to allow digital data transfer to detail design agents.

To achieve the objective, an extensive analysis of current and future modeling and analysis requirements is being performed. The result of this effort will be modeling requirements for the product model (what needs to be in the model in order to support the analysis) and the interface definition for the analysis programs (where is the data and how does the analysis program get it). This defines the protocols for each particular analysis area.

Scope

The scope of the MAPs project includes all ship definition data and analysis from concept through contract design. It is intended that some contract design data will then be available in digital form to prospective design agents. However, some data defined by MAPs may not be transferred, specifically those data elements pertaining to analysis loading (inputs) and analysis results. For example, a specific pump's location, orientation, and flow rate may be transferred, but the analysis inputs and results specifying the exact flow rate of the pump in the overall system are not. Another example: the contract design weight report (the weight analysis result) generated by NAVSEA is not given to the detailed design agent but is used as a comparison to the detailed design weight report produced by the design agent.

Analysis loading and results must be stored to allow redesign at a later date.

When the MAPs project began in April of 1990, the CAD 2 contract was not yet awarded. The CAD 2 specification identified several modeling and analysis requirements, but exactly how these requirements would be fulfilled by the contract award winner was unknown . The MAPs project concentrated on defining data needs and data formats for a given analysis area, but an actual implementation of the analysis area would have to wait for the CAD 2 systems to arrive. Over 160 CAD 2 systems are scheduled to arrive this fiscal year, and several analysis areas previously MAPped will be implemented on the CAD 2 system by the end of FY 92.

MAPs is also participating with NIDDESC (Navy/Industry Digital Data Exchange Standards Committee) to allow contract design data to be passed to the shipbuilders and to allow detail design and logistics data to be fed back into design. Moreover, in order for NIDDESC to be completely successful in transferring contract design data, that data must first be formally defined. Some members of the MAPs team are also part of NIDDESC, and MAPs has borrowed some data models developed by NIDDESC as starting points. Further information on the NIDDESC efforts can be obtained by contacting SEA 507.

Overall Goal

The overall goal of the MAPs project is to allow development of product model information in distributed databases in which data is created by the cognizant design code and is used by many other design codes, thereby eliminating unnecessary work and errors associated with redundant data.

PROCESS

The process used in the MAPs project is based on Information Engineering (IE) principles. A good definition of IE is as follows:

Information Engineering consists of:

1. *Planning, which is used to define the resources (data, application, technology, personnel) needed to support the business*
2. *Data modeling, a technique used to establish the data requirements of a new systems request [also used to determine the data requirements of an existing system]*
3. *Process modeling, a technique used to define the logic needed to add, delete, modify, and retrieve data defined in the data model*
4. *Enterprise modeling, a technique for building models of all data within the organization [12]*

The planning part of the above definition is the primary responsibility of SEA 507 (Computer Aided Engineering (CAE) Division) in support of ship design and engineering, with support from SEA 05K (Engineering Data Support Office) and SEA 04I (Information Technology Office). These planning efforts are ongoing, and further described in the Technical Support Plan [13] and the NAVSEA Information Resources Strategic Plan [14].

Major analysis areas were identified using the Standard Statements of Work (SSOW) Work Breakdown Structure (WBS) [15]. The selection of each analysis area was based on the ship design process and the availability of Navy TPOCs with the knowledge of each analysis area. The initial priorities are shown in Table 1. Priorities changed as the project continued and the SSOW are continually being revised.

Table 1

SSOW WBS	Analysis/Design Areas	MAPs Priority
A1	Design Management	3
B1	Design Integration	3
B2	Computer Applications	3
B6	Master Equipment List	3
B7	Reliability, Maintainability, and Availability	2
C1	Ship Arrangements	2
C2	Weight Engineering	1
C3	Hull Form and Hydrodynamics	2
C4	Stability	2
C5	Ship Protection	3
C6	Noise and Vibration	3
C7	Damage Control	3
C11	Structures	2
D1	Propulsion Systems	3
D2	Machinery Arrangements	3
D3	Industrial Facilities	3
D4	HVAC	2
D5	Fluids	3
D7	Electrical	2
D12	Replenishment Systems	3
E1	Combat System Integration	2
E5	Combat System Block Diagrams	3
E6	Combat System Space Arrangement	1
E11	Electromagnetic Compatibility Analysis	3
S1	Ship Specification and CDRLS	2

The MAPs project limited its efforts to defining the data needs of each analysis area and the data passed to and from that analysis area. It is important to note that the whole analysis area was considered, not just that analysis that was supported by a given computer program. This will help to define those design areas that could be automated, thus improving the design process. The project followed these steps for each analysis area:

Information Model - determine data requirements, data products and shared data elements

Database Definition - define the data format and access to each data element

Process Implementation - create the specific application using a specific software and hardware solution

Since the implementation of the analysis program is dependent on a suitable computer system, the implementation is being postponed until sufficient numbers of CAD 2 platforms are available. Several MAPped areas are now being implemented on the CAD 2 platform this fiscal year.

Recently there has been a lot of discussion concerning process improvement. There have been several attempts to model the ship design process, with little success [16]. To gain a general insight of data flow through an analysis area, a process overview was generated using the IDEF0 [17] methodology. An example of an IDEF0 diagram is shown in Figure 2. The processes indentified on a IDEF0 diagram can be implemented by hand or with the aid of a computer system. An actual implementation of the analysis (realizing the analysis using a computer system) is dependent on the computer system used. Regardless of the process used to generate the data in the ship product model, that data must be defined. Moreover, by defining the data content by way of an information model of an analysis area makes it easy to implement the analysis process.

Information Model

The data content defined for an area is known as an information model. The main purpose of an information model is to document an understanding of all the data requirements so as to permit unambiguous communication. Another purpose is to organize local facts into a global network showing how they are all related.

Using NIAM

NIAM (Nijssen's Information Analysis Method) is a data modeling method [18]. In defining the data needs for an

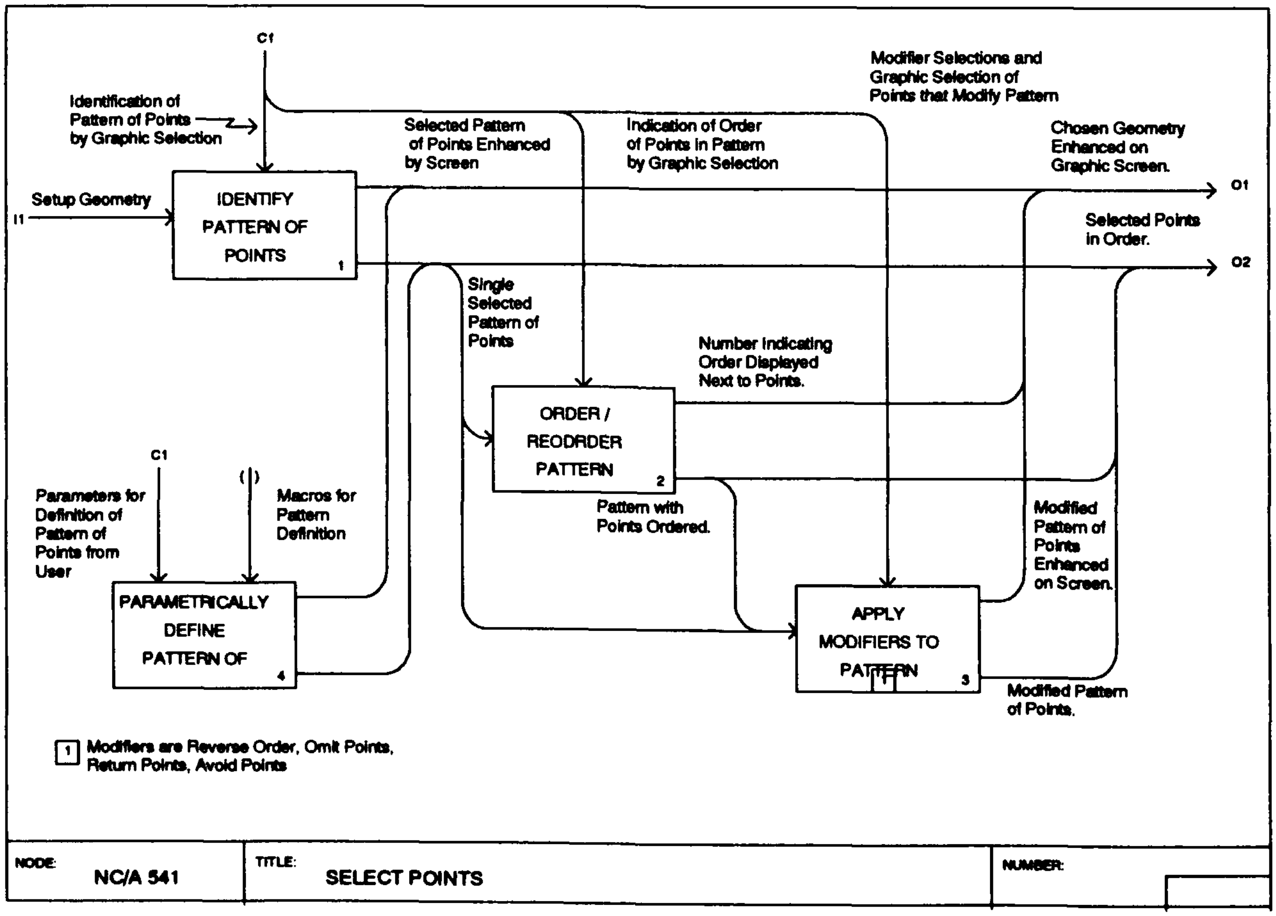


FIGURE 2 - SAMPLE IDEF0 DIAGRAM

analysis area, NIAM is used to describe all aspects of data needs and their relationships with other data. By the use of NIAM, the data requirements of the analysis area are modeled and integrated with an overall conceptual information model comprising all of the other areas previously modeled. This information model identifies the required information and its interrelationships in order to perform the analysis. An example of a NIAM diagram is shown in Figure 3.

Another data modeling method is IDEF1X [19]. Although both can be used to model data elements and their relationships, NIAM is more expressive and allows the modeling of higher level relationships and constraints among data elements. CASE tools supporting NIAM can generate an IDEF1X model if necessary, but additional information must be added to an IDEF1X model to convert it to a NIAM representation. Two NIAM CASE tools are being used for the MAPs Project: PC-IAST [20] (PC-based) and RIDL [21] (Unix workstation based).

The information model developed using NIAM is a lasting record of the data requirements of the analysis area. This information model is independant of any particular computer system context or form. With a little training, a NIAM diagram representing the information model can be readily understood [22].

Integration of Information Models

After an area has been MAPped, the resultant information model can be integrated with previous information models to obtain an overall model, known as a conceptual schema. When MAPping (information modeling) each analysis area, the common data elements can easily be defined. For example, hydrodynamics and stability share common information about a ship hull. Ownership of different data elements (who creates the data elements) can easily be identified.

Some surprising facts were discovered in MAPping certain areas. For example, the seemingly unrelated analysis areas of HVAC and Noise were found to need similar data in order to perform their analysis. HVAC needs to know the area between two compartments and the insulation of the common wall to determine the heat transfer between the compartments. Noise also needs to know the area between the compartments and the noise insulation of the common wall to determine the noise transferred. The development of this common wall area data is the most time consuming effort of

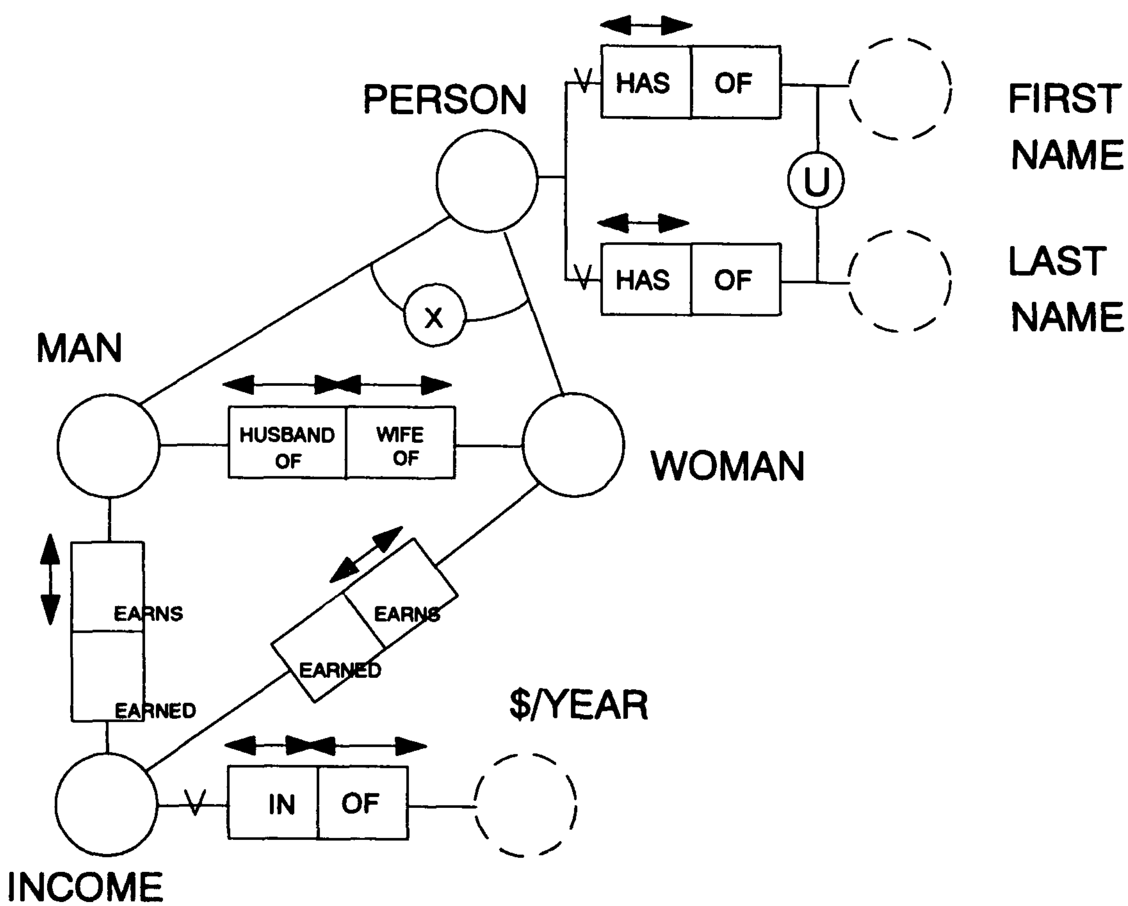


FIGURE 3 - EXAMPLE NIAM DIAGRAM

the analysis, so much so that the analysis is rarely completed in time to affect the design. Consolidating and perhaps automating this effort would result in a better and more timely design.

Define Data Format

After the information model has been verified for consistency using the CASE tool, an actual database can be generated. The output of the NIAM analysis can be the actual statements necessary to define a relational database using a commercial RDBMS (Relational DataBase Management System). The advantages of using a RDBMS to store the data are numerous. The data can be readily entered, modified, and queried. Standard reports can be generated. The data can easily be extracted to feed an analysis program. Data can be shared among different analysis areas. Each CAD 2 workstation comes with an RDBMS and networking tools to share data amongst other workstations. Storing data in just one area ensures that data is not duplicated.

The weights' analysis area was the first area to be MAPped. The current analysis program, SDWE (Ship Design Weight Estimating) uses a text file that stores weight items of a current ship design. SDWE reads this file and generates several weight reports about the current ship design.

Using NIAM, a relational database was formed by modeling the same information in the SDWE file. The required weight reports were generated using the RDBMS reporting tools, completely replacing the SDWE program, which was written in FORTRAN. The weight data was also easier to input and modify using the RDBMS than by editing a text file. Many other reports and ad hoc queries on the data are possible now that the weight data resides in a RDBMS.

However, not all data can be readily stored and manipulated by an RDBMS, as in the weights analysis. Graphical data is stored in a different format to allow speedier access. Analysis programs may store their data in a special file to allow faster execution time. Therefore the data identified by MAPs may eventually reside in a RDBMS, a graphical database or in some specific file format for a given analysis program. Fortunately, the CAD 2 platform has a strong link between the graphical database and the RDBMS. For example, the graphical representation of a pump can reside in the graphical database, whereas non-graphical information about that pump such as flow rate, weight, and electrical load can be stored in the RDBMS. The pump's graphical and non-graphical attributes can be queried by the designer at any time.

The data for a particular design is envisioned to be distributed in several databases around NAVSEA. For example, if the topside designer required the current hullform of a design, he would access the hullform database and receive the current version. These separate databases are shown graphically in Figure 1, with MAPs defining the format and location of the data.

Security and configuration control are inherent in the CAD 2 platform. However, security requirements will require a separate duplicate database at a secure design site for some designs.

Implement Process

Using the data content and format defined using the above steps the analysis process can then be implemented. As described above, weights was the first analysis area modeled. The process of weight analysis was easily implemented using a commercial database. Other analysis areas, such as hydrodynamics or electromagnetic engineering use proprietary or complex analysis programs that cannot use a RDBMS directly or use the graphic data as defined by the CAD 2 system. Some integrated analysis programs such as piping fluid flow and structural finite element modeling and analysis (FEM/FEA) are included on the CAD 2 contract. This integrated analysis capability, along with other third party commercial analysis programs will be used to the greatest extent possible, but the need for specialized Navy-only analysis programs will continue. There are basically three approaches to integrating these specialized analysis programs into the overall design system:

1. **Manual** - Enter the data generated on the CAD 2 system to the analysis program manually. This is acceptable if the amount of the data entered is small and few design iterations are expected.

2. **Via Translator** - Write or use an existing translator to transfer data to the analysis program. This is acceptable if there are few design iterations and the data transfer is as complete as possible. The analysis program does not need to be modified in this case.

3. **Direct** - Rewrite the analysis program to access the data directly. This is essentially what was done for the weights implementation and for several of the integrated analysis capabilities of the CAD 2 system. An integrated analysis capability allows many design iterations to be performed, thus improving the design.

Obviously the technically preferred approach would be to directly integrate the analysis capability into the CAD 2 system. However, it may prove costly to convert the analysis program. Also, by having the analysis program use the CAD 2 data directly ties the program to that computer architecture. Many Navy specific analysis programs are used widely throughout the design community, and not everyone will have or be able to afford a CAD 2 system. For this reason, it may be more economical to support the analysis program via translator or manually. Each analysis area will be evaluated individually as to the best method of implementing the analysis capability.

Team

The MAPs team consists of several contractor information specialists and Navy subject matter experts. A Navy TPOC is identified as the subject matter expert for each analysis area. Training in information modeling using NIAM was given to the team and several prospective Navy TPOCs.

The MAPs team is concerned with what data is used in the analysis, not how it is analyzed. Nevertheless, the MAPs team encountered some resistance in attempting to MAP certain areas. It would have helped to have some of the MAPs team to be Navy personnel, but no Navy personnel with the appropriate expertise were available.

The MAPs team, (or, as they prefer to be called, cartographers) has formed into a very cohesive unit. They have obtained an extremely valuable knowledge of the data elements used in a ship design. The Navy TPOCs have also benefited from MAPping their analysis areas, thereby gaining a greater understanding of the data elements in their area and how their data interacts will other analysis areas.

PROCESS IMPROVEMENT

The implementation of ongoing process improvement should be the goal of every organization [23]. Improvement is change for the better. And change, for whatever reason, means uncertainty and fear. The introduction of the CAD 2 systems into NAVSEA is filled with many uncertainties. Getting the engineers involved in the implementation and utilization of these computer tools is the key to successful implementation.

In order to most effectively integrate the CAD 2 systems into the ship design process, SEA 05 has initiated the Design System Development Project [24]. This project has an organization of members similar to an actual ship design, with a Ship Design Manager, Task Group Managers and Task Leaders. Approximately 90 percent of the emphasis will be on design process improvement using CAD 2 vice design data development. The Design System Development Project will use the information models developed by the MAPs project as a starting point.

CONCLUSION

The MAPs project has accomplished many of its original goals. Several analysis areas are being implemented on the CAD 2 system with the help of the MAPs groundwork. We now have a better understanding of the overall data requirements for the ship product model.

Any future analysis requirements can easily be integrated into the existing information models. Because the data exists in a format that can be easily queried, many types of analysis that were previously impossible or inconceivable are now feasible.

The implementation of the various analysis programs integrated on the CAD 2 platform will allow concurrent engineering to become a reality.

Acknowledgments

The author would like to thank all persons involved in the MAPs project, including the Cartographers, the Navy TPOCs, and NIDDESC. The author would especially like to thank the members of SEA 507 whose support and encouragement of the MAPs project has been unflagging.

References

[1]. Webster's Ninth New Collegiate Dictionary, 1990, pp762, definition 10b.

[2]. Websters's Ninth New Collegiate Dictionary, 1990, pp 82, definition 2a.

[3]. Websters's Ninth New Collegiate Dictionary, 1990, pp 947, definition 3b.

[4]. Dertouzos, Michael L., "Communications, Computers and Networks", Scientific American, Sept. 1991 pp. 62-69.

[5]. Billingsley, Daniel W. et. al. "Revolution at NAVSEA - Managing Design and Engineering Information", presented at the SNAME/ASE Naval Ship Design Symposium, 25 February 1992.

[6]. CSD Software Design Specification, NAVSEA 507 NAVSEA Technical Note 068-507-TR-0001, October 1989.

[7]. Brucker, Blain R., Merrill K. J., "Computer Integration of SEAWOLF Class submarine Life-Cycle Functions", Journal of Ship Production, Vol. 7, No. 1, February 1991.

[8]. NIDDESC Ship Piping Application Protocol, Version 0.6, Navy-Industry Digital Data Exchange Standards Committee, October 1991

[9]. Schmidt, W.R., Shields, R.V. III, and Vander Schaff, J. R., "Modeling and Transfer of Product Model Digital Data for the DDG 51 Class Destroyer Program", Proceedings, SNAME Ship Production Seminar, August, 1990.

[10]. EM Engineering Baseline 1 Architecture, Final Technical Report, NAVSEA 06K.

[11]. Integrated Database (IDB) Volume 2: Schema Definition, SofTech, Inc. NAVSEA 068-501/CSD-TN-0002 October 1984.

[12]. Kerr, James M. "Engineering Solutions", Information Week, November 18, 1991 p58.

[13]. Technical Support Plan, Computer Aided Engineering Division (SEA 507), Naval Sea Systems Command, Washington, DC 1 July 1991.

[14]. NAVSEA Information Resources Strategic Plan, Naval Sea Systems Command, Washington DC, 1 October 1991.

[15]. NAVSEA Memorandum OPR: 50P Serial 50P/067 dated 19 DEC 1990. From SEA 05B, Subject: Standard Statements of Work.

[16]. Ryan, J. Christopher, Jons, Otto P. "Improving the Ship Design, Acquisition and Construction Process", Naval Engineers Journal, March 1992.

[17]. "Integrated Computer-Aided Manufacturing Architecture Part II, Volume IV - Function Modeling Manual", AFWAL TR-81-4023, SofTech, Inc. June 1981.

[18]. Nijssen, G. M., and Halpin, T. A., Conceptual Schema and Relational Data Base Management, a Fact Oriented Approach, Prentice Hall of Australia Pty Ltd., 1989.

[19]. Integrated Computer-Aided Manufacturing Architecture, Information Modeling Manual IDEF1 - Extended (IDEF1X), D. Appleton Company Inc. 31 December 1985.

[20]. PRECISE* PC-IAST User's Guide, Control Data Corporation, June 1990.

[21]. RIDL* RIDL-G Users Guide, IntelliBase, Doc Nr RIDL 4 - RG 91.4.1 - PV910322.

[22]. Thompson, Paul, "Natural Language Analysis, Information Modeling, and Database Engineering: A Gentle Introduction for Newcomers", 1986. (Copies available from SEA 507 by arrangement with the author)

[23]. Goldratt, Eliyahu M., Cox, Jeff. The Goal, North River Press, Inc. 1984, 1986.

[24]. NAVSEA Memorandum OPR: 507 Serial 507/002 dated 2 February 1992, from 05B, Subject: Design System Development Project.

CORROSION CONTROL CONSIDERATIONS FOR U.S. NAVY SHIP DESIGN

Beau Brinckerhoff
Materials Engineer
Corrosion Control Division
(SEA 5141)
Naval Sea Systems Command

May 1992

Approved for Public Release
Distribution Unlimited

The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense nor the Department of the Navy

Abstract

This paper provides general information about corrosion control considerations for U.S. Navy ship design. The results of several studies to estimate the monetary costs of corrosion are provided. Fundamental corrosion principles are presented and the types of corrosion commonly encountered in the marine environment are discussed. Also, specific methods to help prevent corrosion of materials in shipboard applications, such as use of cathodic protection, are discussed. Some of the new challenges in shipboard corrosion control, such as the need to comply with environmental regulations for coatings, are also discussed. In closing, the paper explains that the lowest life cycle cost can best be achieved by considering corrosion control early in the design process.

LIST OF TABLES AND FIGURES

LIST OF DEFINITIONS AND ABBREVIATIONS

Ag/AgCl	Silver/Silver Chloride
CRES	Corrosion Resistant Steel
DTRC	David Taylor Research Center
HAC	Hydrogen Assisted Cracking
ICCP	Impressed Current Cathodic Protection
NAVSEA	Naval Sea Systems Command
OM&N	Operations and Maintenance, Navy
VOC	Volatile Organic Compound

COSTS OF CORROSION

The primary goals of shipboard corrosion control are to prevent or reduce corrosion of materials in order to help assure mission completion, to reduce the maintenance burden, and to minimize life cycle costs.

Impact on mission completion

Excessive corrosion of materials can result in structural or other type failure of shipboard components. Corrosion of critical components can contribute to system failure and impede mission completion. Also, to accommodate maintenance work to fix excessive corrosion incurred unexpectedly, scheduled drydockings may need to be extended thereby impacting ship mission.

Monetary costs

The monetary costs of corrosion are incurred in maintenance dollars required to restore corroded materials to acceptable form. We do not know for certain the losses sustained by the Navy as a result of corrosion because no single authority tracks such statistics and since measures of corrosion repair efforts are uncommon. However, costs of corrosion have been estimated. The following reports the results of several studies pertinent to the military:

The National Bureau of Standards reported in 1978 that it is very likely that the monetary costs of corrosion to the military services amount to 8 billion dollars per year [1]. Based on this figure and on OM&N inflation index factors of reference [2], and assuming all other factors equal, the annual cost of corrosion sustained by the military services will reach 21 billion dollars by the year 2000.

In 1990 the results of a study to determine the annual direct cost of corrosion maintenance for weapon systems and equipment in the U.S. Air Force were reported. The study indicated that the Air Force incurs $718 million per year as a result of direct corrosion costs. Included in this estimated cost were expenses associated with washing, application of preventative compounds, environmental sealing and repair of corrosion damage. Excluded from the estimated costs were expenses associated with hardware and depreciable equipment [3].

In 1987, extensive corrosion damage to the hull of USS New Jersey (BB-62) was reported. The cause of corrosion was attributed to coating failures and insufficient cathodic protection capacity for the service period experienced. Informal reports indicated that the damage incurred by corrosion cost millions of dollars to repair.

Although the accuracy of the above estimates can be questioned, it seems reasonable to conclude that the monetary costs of corrosion to the Navy is quite significant. In view of this and the possible adverse impact corrosion can have on ship mission, efforts to prevent or reduce corrosion are worthwhile.

FUNDAMENTAL CORROSION PRINCIPLES

An understanding of the fundamental corrosion principles applicable to the marine environment will aid the ship design engineer in achieving a system which meets the necessary service requirements and operates at the lowest life cycle cost. The following paragraphs provide a brief overview of these principles. For greater detail and a better understanding, the reader is directed to the documents referenced in this paper.

Definition of corrosion: Reference [1] defines corrosion as: "a deterioration of a material (usually a metal) because of a reaction with its environment."

The corrosion process

The predominant process of corrosion in the marine environment is electrochemical in nature; it involves electrical and chemical changes. This corrosion process is caused by an interaction between areas of different corrosion potential on a metal surface or by the corrosion potential difference between dissimilar metals electrically connected and immersed in a common electrolyte. This process is depicted in figures 1 and 2. Figure 1 depicts a common corrosion cell involving different corrosion potentials on the same material. The disparity in potentials could be the result of chemical inhomogeneity on the surface resulting in anodic and cathodic areas on the same metal surface. Figure 2 depicts a common corrosion cell involving two materials with dissimilar corrosion potentials. In this case, the anodic area is on one material and the cathodic area is on the other material.

Examination of figures 1 and 2 reveals four critical elements of the corrosion process.

(1) Anode - The metal surface which corrodes by an oxidation reaction, donates electrons, and releases metal ions. This reaction is presented in equation 1.

Equation 1:

$$M \longrightarrow M^{++} + 2e'$$

(2) Cathode - The metal surface at which reduction occurs and electrons are consumed; among other cathodic reactions, hydrogen ions may be converted to hydrogen gas. This reaction is presented in equation 2.

Equation 2:

$$2H^{+} + 2e' \longrightarrow H_2$$

(3) Electrolyte - The common solution which contacts both the anodic and cathodic surfaces and is capable of conducting electricity. In marine applications, the electrolyte involved in the corrosion cell is usually seawater.

(4) External Electrical Conductor - The current path which transfers the electrons between the anode and cathode. The ship's ground or like conductive material may act as the external electrical conductor.

Elimination of any one of the four critical elements will make electrochemical corrosion impossible. All methods of controlling electrochemical corrosion work toward eliminating or affecting at least one of these elements.

The tendency to corrode

A very general idea of the relative corrosion resistance of metals can be determined by review of the galvanic series. The galvanic series provides corrosion potentials of selected metals and metal alloys in a particular environment. However, these potentials, and even the relative ranking of metals, can change due to environmental changes, such as changes in flow or salinity. Because of this, the galvanic series is not always a reliable indicator of galvanic compatibility of materials. For example, alloy 625 and K-Monel (both nickel based alloys) are relatively similar and extensive galvanic corrosion would not be indicated by review of the galvanic series. However, we know from recent testing at the Naval Surface Weapons Center (formerly DTRC) Annapolis, MD that K-Monel can corrode extensively when coupled to alloy 625 and immersed in seawater [4].

Pertinent data for Navy applications is provided by Table 1 which reports mean corrosion potentials in quiescent seawater.

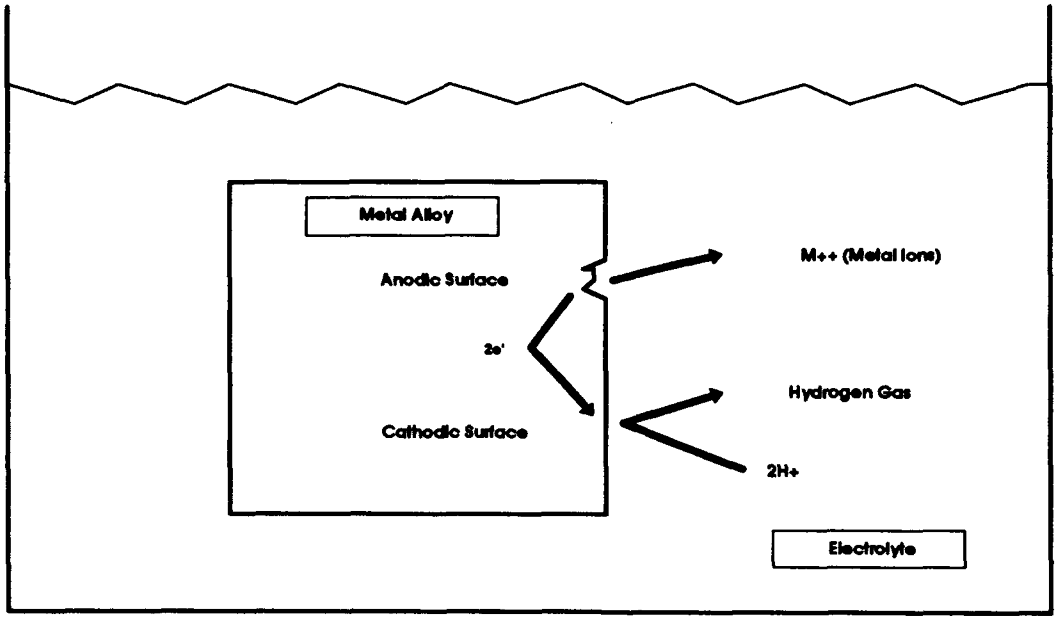


Figure 1. Corrosion Cell Involving Different Corrosion Potentials On The Same Material

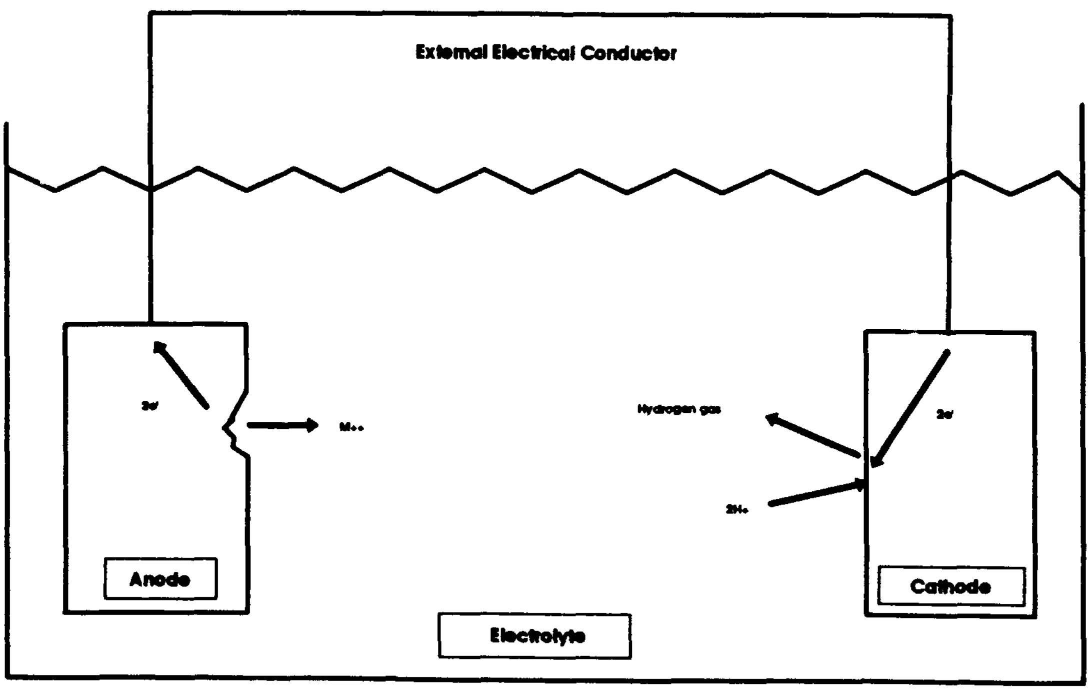


Figure 2. Corrosion Cell Involving Two Materials With Dissimilar Corrosion Potentials

TABLE 1

GALVANIC SERIES

Mean Open-Circuit Potential (volts)[1] Versus Ag/AgCl Reference Electrode In Quiescent Seawater

Zinc anode alloy	- 1.05
Tin	- 0.70
Mild steel	- 0.65
Muntz metal	- 0.35
Copper-Nickel (90-10)	- 0.30
Aluminum bronze	- 0.25
Copper	- 0.25
CRES 316	- 0.18
Nickel	- 0.18
Monel K-500	- 0.14
Titanium-6Aluminum-4Vanadium	- 0.14
Inconel 625	- 0.08
Silver	- 0.08
Gold	+ 0.14

Note 1: The corrosion potential values presented in this table represent the mean of the range of potentials which have been reported. In reality, the range of potentials for a specific material overlap the range of potentials for other materials. In addition, some passive film forming alloys, such as CRES 316, are reported to show significant shifts in corrosion potential (up to 0.45 volts) due to the change from passive to active state.

Source: Naval Ships' Technical Manual, Chapter 633, Cathodic Protection, 1 October 1985.

Rate of corrosion

By Faradays law, the amount of corrosion (weight of metal reacted) is defined by the following equation [5]:

Equation 3: (Faraday's Law)

$$\text{weight of metal reacting (g)} = kIt$$

where: k = electrochemical equivalent (g/coulomb)

I = corrosion current (amperes)

t = time (seconds)

Applying knowledge about the density and geometry of the metal, Faraday's law can be used as the basis for the following equation:

Equation 4:

$$\text{rate of thickness loss (cm/s)} = \frac{kI}{d\,(S.A.)}$$

where: k = electrochemical equivalent (g/coulomb)
I = corrosion current (amperes)
d = density (g/cu.cm.)
S.A. = surface area of corroding metal (sq.cm.)

Corrosion current can be affected by changes, including surface area changes, at the anode and/or cathode. However, for the purpose of this discussion we will consider the corrosion current to be unaffected by changes in anode surface areas.

Examination of equation 4 will reveal that corrosion rate is dependent on the surface area of the anode: as the anode surface area is increased, the rate of thickness loss decreases. On this basis, the following generalization normally holds true: If a large anode-to-cathode surface area ratio exists, the corrosion rate will be relatively small. If a small anode-to-cathode surface area ratio exists, the corrosion rate will be relatively large. Efforts to predict corrosion rates have been accomplished by numerical methods based on Faraday's Law. For new design, such methods may provide the only means of predicting the acceptability of a given material combination. It may also provide the only means of planning for inspections and repairs aimed at correcting corrosion problems before they result in failure of the component or system.

TYPES OF CORROSION COMMONLY ENCOUNTERED IN THE MARINE ENVIRONMENT

Uniform corrosion: As the name indicates, this form of corrosion proceeds uniformly over the entire surface. It is normally the most predictable form of corrosion since it involves a known surface area [1].

Galvanic corrosion: Most forms of corrosion involve galvanic corrosion; they involve the four critical elements depicted by figures 1 and 2. Galvanic corrosion results when surfaces of different electrical potentials are electrically connected and in a conductive electrolyte. The surfaces of different potential can exist on the same body or on distinct bodies. Galvanic corrosion is usually most pronounced at the anode surface closest to cathode surface [1].

Atmospheric corrosion: Atmospheric corrosion can occur on topside and other areas of ships which are not immersed in seawater, but are exposed to the atmosphere. In this case the electrolyte required to sustain corrosion is normally supplied by seawater splash, condensation, or weather conditions. Atmospheric corrosion is normally most pronounced in areas which retain water and/or which involve dissimilar metals [1]

Pitting corrosion: Pitting corrosion is evidenced by extremely localized corrosion and normally initiated at anodic points on a metal surface. This form of corrosion is extremely difficult to predict since the affected surface areas are not known. Since a relatively small amount of anode surface area is involved, the rate of thickness loss (at the local corrosion sites) can be very large [1].

Crevice corrosion: Crevice corrosion is characterized by intense localized attack within crevices and generally occurs only on alloys normally considered resistant to corrosion (passive film formers). Several proposed mechanisms for crevice corrosion exist. One of those favored involves four stages of crevice corrosion as follows [1,6]:

(1) depletion of oxygen in the crevice solution;

(2) increase in acidity and chloride content of the crevice solution;

(3) permanent breakdown of the passive film and the onset of corrosion;

(4) propagation of crevice corrosion.

Stress corrosion: Stress corrosion results from the simultaneous action of a corrosive agent and stress. Several models explaining the mechanism of stress corrosion exist. One model explains that propagation of cracks occurs due to the repeated formation and rupture of a brittle film growing at the crack tip [7].

Erosion-corrosion: This form of attack involves corrosion accelerated by erosive action. It is commonly encountered when particles in a liquid impinge on a metal surface which causes wearing away of protective films which would normally prevent or reduce corrosion. Once the film is worn away, new reactive surfaces are exposed which are anodic to uneroded adjacent surfaces. It is sometimes observed on surfaces which are subject to turbulence caused by sharp turns or other abrupt changes in flow [1].

Biological corrosion: The chemical reactions associated with the normal metabolism of microorganisms, bacteria, yeasts, algae and other organisms can cause biological corrosion. For example, the metabolism of certain bacteria causes oxidation of inorganic compounds such as iron, sulfur, and hydrogen [1].

Other forms of corrosion have been classified (such as intergranular corrosion, corrosion fatigue, and high temperature corrosion) but are perhaps less common in Navy applications. The reader is directed to the referenced documents for a more thorough discussion of the various forms of corrosion attack.

PRIMARY CORROSION CONTROL METHODOLOGIES

Material selection

Successful performance of shipboard systems depends, to a large extent, on the materials used to construct the systems. Issues such as strength, wear properties, environmental compatibility, and corrosion control require consideration. The goal of material selection is to find the most cost effective option while providing acceptable performance.

For example, if the system must be refurbished every five years for reasons other than corrosion, it may not make sense to choose an expensive, corrosion resistant material which could provide service for the life of the ship (30 years). Conversely, if the system is intended to provide service for the life of the ship without refurbishment, it would be inappropriate to select a material which would provide service for only five years before unacceptable amounts of corrosion occur. As another example, corrosion resistant steel (CRES) usually performs satisfactorily in topside applications. But CRES can experience extreme pitting when immersed in stagnant seawater. Therefore, selection of CRES material is appropriate for some shipboard applications, but not for all.

In addition to use of materials with adequate corrosion resistance for the application, another criteria for material selection is to avoid use of dissimilar materials wherever possible since use of dissimilar materials can result in galvanic corrosion.

Physical design

The physical design and layout of the materials can greatly influence the susceptibility of the system to corrosion. Efforts to avoid designed-in corrosion problems can help reduce future costs. Several examples of physical design issues are presented in figure 3. As depicted in figure 3a, efforts to avoid sharp corners is recommended to avoid areas of stagnation in the system, to facilitate cleaning, and to facilitate application of coatings if required. As depicted in figure 3b, avoidance of crevices is recommended to preclude possible problems associated with crevice corrosion. In topside environments, as depicted in figure 3c, avoidance of joint designs which result in entrapment of moisture is recommended to prevent prolonged exposure to water [1].

Barrier coatings

Barrier coatings provide a barrier between the electrolyte and the anodic and/or cathodic surfaces. This helps reduce the amount of corrosion current passed thereby reducing corrosion. Barrier coatings can be classified into three groups:

(1) Inorganic or conversion coatings;

(2) Metallic coatings;

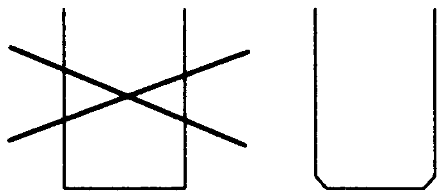


Figure 3a. Avoid sharp corners to avoid areas of stagnation, to facilitate cleaning, and to facilitate application of coatings.

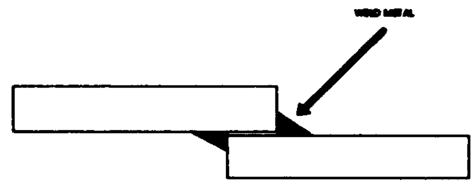


Figure 3b. Avoid exposed crevices. One remedy is to apply weld metal to the entrance of all crevices.

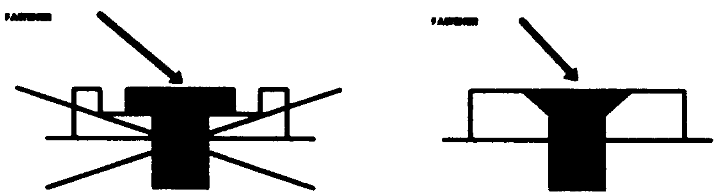


Figure 3c. Avoid joint designs which result in entrapment of moisture.

Figure 3. Physical Design

(3) Organic coatings.

Inorganic or conversion coatings are produced by applying chemical solutions which convert the metal surface to a protective film. Metallic barrier coatings normally involve use of noble metals to protect relatively less corrosion resistant metal surfaces, such as the use of chrome plating on steel. Organic coatings include paints, varnishes and other similar compounds [1].

To get good performance, coatings must be properly applied. In fact, most of the coating failures in the Navy and industry are attributed to improper application rather than to poor material quality. Proper application involves careful attention to surface preparation and application restrictions, such as surface temperature and humidity level. Some of the application methods commonly used to apply barrier coatings are brush or spray (paint), electroplate (metal coatings), thermal spray (metal or metallic- ceramics coatings), and weld overlay (metal coatings). The choice of material and application procedure depends on many factors such as substrate material (the material requiring protection), temperature, likelihood of abrasion, service period, and criticality of the application.

Partial failure of coatings on anodic surfaces can result in excessive localized corrosion due to the unfavorable anode-to-cathode surface area ratio which can result. Partial failure of coatings on cathodic surfaces usually does not result in unfavorable anode-to-cathode surface area ratios and, therefore, is not as much a concern. Therefore, in immersed conditions in which galvanic corrosion is a concern, it is sometimes recommended to coat cathodic surfaces but not anodic surfaces.

Cathodic protection

Cathodic protection can essentially halt electrochemical corrosion by electrically changing the surface of the material protected, but can only be applied in wetted applications. In non-wetted applications, the electrolyte required to transfer the corrosion current does not exist and, therefore, cathodic protection cannot work.

The following paragraphs discuss three common types of cathodic protection systems used by the Navy: Impressed Current Cathodic Protection (ICCP), sacrificial anodes, and sacrificial coatings.

ICCP systems are used by the Navy to prevent corrosion of ship hulls. Unlike sacrificial systems, ICCP systems require a power source to provide the current necessary to prevent corrosion. Normally these systems are automatically controlled to a predetermined electrical potential versus the systems reference electrode. Physical scale modeling, which involves use of a scale model of the ship hull (complete with bare metal surfaces representative of normally encountered hull conditions such as paint loss on the leading edges of rudders), has been found to be an effective way to optimize design of hull ICCP systems.

Sacrificial anodes are used for cathodic protection on most, if not all, of the ships in the Navy. They are installed to help prevent corrosion of hulls and metal structures in such locations as ballast tanks, bilge areas, and machinery. Sacrificial anode systems are self regulating in that they provide protective current when needed based on differences in electrical potential; no monitoring or outside control is required. To help ensure proper distribution of current, the anodes are normally distributed evenly over the surfaces requiring protection.

Sacrificial coatings such as thermal sprayed aluminum are usually applied in topside or non-immersed applications. In immersed applications, the coatings can rapidly deplete, therefore, other cathodic protection methods (not so easily depleted) are usually favored. Unlike organic coatings, when a sacrificial coating is scratched or otherwise compromised, it can provide cathodic protection to the exposed base metal. Also, to prevent premature depletion of sacrificial coatings, organic coatings are sometimes applied as a topcoat.

Some high strength materials are susceptible to Hydrogen Assisted Cracking (HAC) as the result of stress, time, the evolution of hydrogen on it's surfaces and other factors. Since cathodic protection can result in evolution of hydrogen due to cathodic reactions, use of cathodic protection on or nearby some high strength materials is to be avoided. This can present a dilemma when the high strength material requires corrosion control in immersed seawater conditions. When such a situation arises, corrosion control methods other than cathodic protection are favored.

Corrosion Inhibitors

Inhibitors stop or reduce corrosion by inhibiting the cathodic and/or anodic processes. They may be applied in various forms, including in paints, sealing compounds, or insulating materials.

NEW CHALLENGES

In an attempt to achieve improved performance, lower cost, and/or comply with environmental and health regulations, the Navy has pursued the use of new materials and new applications of materials. Some examples follow:

Volatile Organic Compound (VOC) content in coatings

In general, some type of solvent is needed to facilitate coating application. The solvent is released while the coating cures. The impact of release of such solvents to the environment has been under increased scrutiny by many, including lawmakers. The Navy is actively pursuing environmental issues and efforts currently on- going include the following:

(1) Compliance with all local, state, and federal regulations concerning VOC content in coatings.

(2) Investigation of transfer efficient application methods which reduce VOC emissions during application of coatings.

(3) Investigation of water borne paints and coating technology which have lower VOC content.

New material combinations

New materials are usually proposed to meet specific design criteria such as high strength, wear resistance, or corrosion resistance. These materials are often relatively expensive because they require special processing or expensive raw materials and use of them throughout a system might not be possible due to limited construction funds. In addition, a system might require use of several different materials since no one material is suitable for all applications. For these reasons, combination of different materials in one system often occurs.

Combination of incompatible materials in seawater applications can result in excessive corrosion of the less noble material. To avoid selection of incompatible materials, past performance data of the material combination can be consulted. However, when there exists no past performance data, as can be the case when a new material combination is proposed, some amount of corrosion testing to assess the compatibility of the materials (and extent of corrosion) is usually recommended.

New material combinations with relevance to recent ship designs include the following: alloy 625-to-copper-nickel, alloy 625-to- steel, and titanium-to-copper-nickel. Limited evaluations of some of these material combinations have been performed or are on-going. In addition to determining the compatibility of materials, testing can provide an indication of the rate and distribution of corrosion. This data can be used to plan for inspections and corrosion related maintenance.

LOWERING LIFE CYCLE COSTS

The lowest life cycle costs can best be achieved by considering corrosion control early in the design process. This is necessary to ensure that the appropriate materials and physical design are selected. This will help avoid designed-in corrosion problems which are often costly to fix in later stages of design and, if not fixed, can result in system failure and excessive maintenance costs.

In regard to material costs, since corrosion resistant metal alloys usually contain relatively expensive constituents, such as nickel or chromium, they are usually more expensive than materials with less corrosion resistance. However, higher capital costs are often quickly compensated by relatively low maintenance costs. It follows that sometimes the lowest life cycle costs are only realized if somewhat higher capital costs are invested.

ACKNOWLEDGEMENTS

Thanks to Mr. Rich Parks, NAVSEA 5141 for support and Mr. James Rudroff, NAVSEA 51412 for information about VOC.

REFERENCES

[1] Military Standardization Handbook, Corrosion and Corrosion Prevention of Metals, 21 November 1983.

[2] NAVSEA 017 Inflation Data Sheet of January 1992.

[3] Aviation Week & Space Technology, June 24, 1991.

[4] DTRC Ltr Ser 2813/90001 of 13 November 1989.

[5] Uhlig, H.H., Corrosion and Corrosion Control, John Wiley and Sons, Inc, Second edition, 1971.

[6] Oldfield, J.W. and W.H. Sutton, Crevice Corrosion of Stainless Steels, British Corrosion Journal, Vol. 13, 1978.

[7] Latanision, R.M., O.H. Gastine, and C.R. Compeau, Stress Corrosion Cracking and Hydrogen Embrittlement: Differences and Similarities, from Environment Sensitive Fracture of Engineering Materials, Z.A. Foroulis, ed., AIME, 1979.

IMPROVING RMA AND ILS ANALYSIS IN THE SHIP DESIGN PROCESS

Patrick J. Hartman, Ph.D., P.E.
Head, Design Engineering Branch
R&M Engineering Division
(SEA 5121)
Naval Sea Systems Command

Jeffery Gibbs
Senior Logistician
Transition to Production Division
(SEA 5123)
Naval Sea Systems Command

May 1992

Approved for Public Release
Distribution Unlimited

The views expressed herein are the personal opinions of the authors and are not necessarily the official views of the Department of Defense nor the Department of the Navy

Abstract

This paper explores a theoretical level of logistic support designated the Integrated Logistic Support (ILS) Optimal Point (IOP). As with Inherent Availability (Ai), where performance is designed into a system, an economically optimal level of logistic support can be developed to ensure that the difference between Ai and Operational Availability (Ao) is minimized. The cost effective level of logistic effort is the IOP.

NAVSEA 512 has completed a major enhancement of its TIGER Reliability, Maintainability, Availability (RMA) computer simulation which now makes it possible to assess the effect that changes in ILS supply support, equipment design, and maintenance philosophies have on optimal ship availability.

Analysis of total ship RMA performance using TIGER previously required about an hour of processing time on today's mini-computers. The new TIGER requires only a few seconds to perform this analysis with the increased precision required for equipment tradeoffs. The theoretical ILS concepts proposed in this paper can now be demonstrated with TIGER and used to ensure more available and maintainable ships given the reduced resources, extended service lives, and delayed shipyard availabilities foreseen for the Fleet in the coming years.

LIST OF FIGURES

LIST OF TABLES

NOTATIONS/DEFINITIONS/ ABBREVIATIONS

AVAILABILITY - A measure of the degree to which an item is in an operable and committable state at the start of a mission when the mission is called for at an unknown (random) time.

INHERENT R&M VALUE - A measure of reliability or maintainability that includes only the effects of an item design and its application, and assumes an ideal operation and support environment.

MAINTAINABILITY - The measure of the ability of an item to be retained or restored to specific condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair.

MEAN DOWN TIME - MDT is the time necessary to repair a failed system at the organizational level when all the resources (manpower and spare parts, for example) are available and includes the additional delay caused by the logistic support for the system.

MEAN TIME BETWEEN FAILURES - MTBF is the mean operating time between (successive) failures.

MEAN TIME TO REPAIR - MTTR is the average time required to repair a system in its operating environment (when necessary resources are available). MTTR is a quantification of inherent "designed in" system maintainability.

RELIABILITY - The probability that an item can perform its intended function for a specified interval under stated conditions.

TIGER - The NAVSEA Reliability, Maintainability, and Availability (RMA) computer simulation for equipment, parts, and total ship analyses; NAVSEA TE660-AA-MMD-010.

INHERENT INTEGRATED LOGISTIC SUPPORT OPTIMAL POINT (IOP)

This paper will discuss a theoretical point of logistics support which will be called the Inherent Integrated Logistic Support Optimal Point (IOP) of a system or equipment. Inherent signifies the Reliability, Maintainability, Availabilities (RMA) concept of inherent availability (Ai). As with inherent availability, there is an inherently "optimal" level of logistics support. If this level of support is not met, system availability will suffer. Conversely, if a higher level of support is used than this optimal point, then little advantage to system availability will result.

For purposes of this paper, the following ten logistics elements will be considered:

MANPOWER AND PERSONNEL
MAINTENANCE PLANNING
SUPPLY SUPPORT
TRAINING & TRAINING SUPPORT
TECHNICAL DATA
COMPUTER RESOURCES SUPPORT
SUPPORT EQUIPMENT
FACILITIES
PACKAGING, HANDLING, STORAGE, AND TRANSPORTATION
DESIGN INTERFACE

In addition to the above elements, integrated logistic support planning (ILSP) and logistic support analysis (LSA), will be discussed. These ILS functions, when optimized, will lead to a system of equipment approaching its inherent availability. If one or more of the ILS elements are sub-optimized, then operational availability will suffer. If one or more elements are "over optimized," then critical resources are in effect being wasted and reallocation should occur.

An optimal level of logistic effort that ensures a system or equipment will be maintained near its inherent availability, is the key concept to this theory, which is the IOP. Within the overall IOP, each sub-element also has a Element IOP (EIOP) which ensures equipment Ai is approached given that all other elements are at EIOP. An example of this concept is obtaining the minimal number of spares and repair parts needed to fix an equipment or system.

If the spares and repair parts are available when needed, based on the Mean Time Before Failure (MTBF) and the Mean Time To Repair (MTTR), the system approaches its Ai. However, if needed spares and repair parts aren't on hand, the waiting time for these parts will cause equipment availability to be significantly less than Ai. In practice the wait for parts, usually called Mean Logistics Delay Time (MLDT) can be very detrimental to overall system availability. Thus, the goal is to have the parts on hand when needed, but not to buy more parts than required. Thus, if we bought three of every possible spare and repair part, and always kept these on hand, even though MLDT would be zero, this still wouldn't be an optimal level of support. The reason being that by allocating more resources than needed to supply support, the equipment availability still couldn't improve beyond Ai. Because of this, over allocation of resources for spares should be diverted to other elements (unless they are already at EIOP), or above. The same concept holds true for all the logistic sub-elements. Another example would be equipment or system technical manuals (TMs). If the equipment TMs are adequate for equipment maintenance and operation, this subset of IOP is optimized. If the technical manuals are not adequate then sub-optimization of the technical data element will cause Ao not to approach Ai. If this is the case, technical manual changes should be affected to the level needed for operators and maintainers to accomplish their task. In contrast to inadequate technical manuals, if TM's are configured beyond what maintainers and operators need, then there is a waste of resources and optimization isn't achieved. It is important that program offices review technical manual development with the perspective of not only ensuring technical manual adequateness, but also with an objective of eliminating unneeded chapters, sections, etc.

The reader may be asking by this point how they will know when the EIOPs are met. There isn't an easy answer to this question. The only way to have a good estimate is to know what is required of each element. A brief element by element discussion will follow.

MANPOWER AND PERSONNEL (M&P)

This element will be discussed first because in the life cycle cost of most systems and equipment M&P is a major cost driver. M&P is described in DODINST 5000.2 [1] as "the identification and acquisition of military and civilian personnel with the skills and grades required to operate and support a material system over its lifetime at peacetime and wartime rates." The EIOP for M&P, would be the number and type of military and civilian personnel needed to operate and maintain a system in order that the system approaches its Ai given the elements are at EIOPs. If either number or type of personnel are deficient to the point that the system can not be operated or maintained, or operated and maintained with unacceptable long repair times, or more than normal failures, then the M&P EIOP is sub-optimal. Additionally, if more personnel are used than required to reach Ai then the M&P EIOP is not optimal.

More likely than the above situation, is designing equipment without considering manpower impact. If equipment design is such that more or higher skilled personnel are needed than what another design would require, then the M&P is beyond EIOP. To avoid this requires designing the system with M&P optimization in mind. Approaches to optimization include embedded training, human engineering, and reliability and maintainability analysis. These actions should lead to a system design which requires the smallest number of personnel who require the least amount of training. In other words, designing a system that requires two rocket scientists instead of three. Better yet, design a system that requires two engineers instead of two rocket scientists.

Sub-optimization - includes not having the number and skilled personnel required to operate and maintain a system at or near its Ai. If the system was "over optimally" designed (designed without M&P in mind) then the optimal point converts to the number and type personnel needed to operate and maintain the system. This becomes true since the "over optimization" of design due to lack of M&P considerations, becomes part of the system's Ai (Ai is totally based on design and must be supported). The approach to attacking sub-optimization of M&P includes recruiting, training, proper design, scheduling etc. These efforts should be no more or no less than required to achieve an acceptable equipment availability.

MAINTENANCE PLANNING (MP)

DODINST 5000.2 describes maintenance planning as "The process conducted to develop and establish maintenance concepts and requirements for the lifetime of a material system. This process includes development of preventative maintenance task, corrective maintenance task, and determining who will perform the task, and where they will be accomplished." In optimizing the MP EIOP preventative and corrective task will be looked at separately.

Preventative - In optimizing preventative maintenance two areas will be considered: first no more maintenance actions should be planned then is needed to maintain inherent system availability based on MTBF and MTTR. This is a function of Reliability Centered Maintenance (RCM) analysis used to develop preventive maintenance. The second area of concern is to ensure that no more time is taken than needed on these tasks (if it requires a loss of system function) and that it is done at the most efficient maintenance level. This avoids spending more resources than required. The approach to optimization for MP in the preventive maintenance area is to faithfully follow RCM methodology. If these analyses are properly done, optimization should occur.

Corrective - Corrective maintenance, unlike preventive maintenance is not planned. Thus a slightly different approach toward optimization is required. The first concern is that MTTR be kept to a low level. The second concern, like in preventive maintenance is that repairs are accomplished at the most efficient maintenance level determined by a level of repair analysis. The third area, as with, M&P is design.

Design has the most influence on how system Ai is affected. Reliability and Maintainability should be considered in the design. If a system is designed which requires more maintenance than another design (within other design tradeoff parameters) than the system will always require excess resources in the MP area. In other words, it will always take more resources for MP then should have been needed. Also, as with M&P, once a "bad design" is chosen, it becomes part of the system Ai. Regardless of design, once Ai is established, then sub-optimization can be avoided by doing the minimal number of maintenance task at the shortest time intervals which ensures system Ao approaches system Ai.

SUPPLY SUPPORT (SS)

DODINST 5000.2 describes SS as "All management actions, procedures, and techniques used to determine requirements to acquire, catalog, receive, store, transfer, issue and dispose of secondary items. This includes provisioning for initial support as well as replenishment SS." This element, as with the two previous elements, requires separate approaches for the problem of sub-optimization versus excess resources. Also as with the last two elements the danger of excess is most prevalent in design. In the SS area, the approach which will most likely avoid this is the use of standard parts in the design effort. By using the highest percentage of standard parts in the design, several EIOP producing results occur. Both range and depth of repair and spare parts are minimized, and since the standard parts chosen are already within an established Government Supply System, provisioning efforts are reduced as well. Thus if equipment is designed with standard parts, the EIOP should result, and the Ai designed into the system should improve.

Deficient depth and range of parts can lead to excessive MLDT. This will lead to system availability less than what is inherent in the design. Approaches to this problem include: adequate provisioning, parts procurement, storage, and demand forecasting. As discussed earlier, the goal is to obtain and stock the minimal number of parts. If more parts than needed are stocked, then resources are wasted. Given this fact, it is not realistic to expect demand predictions to be perfect, thus safety levels will probably be required. However, they should be minimal within an acceptable level of risk and calculated to achieve the required Ao. Also in order to come closer to the EIOP methods similar to Just-In-Time (JIT) or Materials Requirement Planning (MRP) should be adopted.

Since MRP uses safety levels, this approach may be more in line with military needs. Either method will lead to reduced inventory holding cost and more cost efficient supply support.

TRAINING AND TRAINING SUPPORT

Defined in DODINST 5000.2 as "The processes, procedures, techniques, training devices, and equipment used to prepare military personnel to operate and support a new material system. This includes individual and crew training; new equipment training; and logistics support planning for training equipment and devices, acquisition and installation." The goal of optimization of this element involves exerting the minimal required training efforts needed to ensure that training does not negatively effect system availability. In simple terms, training equipment and devices should be adequate enough to train personnel to operate and maintain the system near its inherent availability. Design again is a major factor in determining the availability which will be supported. In order to have a positive effect on availability, training impact should be considered during equipment design. Building in such recent innovations as embedded training and/or condition based monitoring and maintenance expert systems, can dramatically reduce the resources needed to train personnel over the lifetime of a system. If these devices are not considered while designing the system, it is highly probable that "excess training resources will be required.

Another area of concern is ensuring that resources are minimized in training development. This involves reviewing training course development material not only for adequateness, but also to ensure subject matter is absolutely required for mission accomplishment. As with technical manuals, more is not necessarily better. If training efforts can be reduced without negatively affecting availability, then the funds saved could be better used elsewhere.

As in previous cases, sub-optimization can be avoided within given DOD policies. This includes operational testing to ensure developed training materials and courses prepare operators and maintainers. Course feed back reports could also indicate whether training was adequately developed and executed.

TECHNICAL DATA (TD)

As described in DODINST 5000.2 TD is "recorded information regardless of form or character (such as manuals and drawing of a scientific or technical nature). For purposes of this paper only technical manuals (TMs) will be discussed.

As briefly discussed above, TMs should be developed to adequately support equipment operators and maintainers. This should give us the TD EIOP. The process involved in the effort includes first reviewing TM documentation for technical content and useability. Second, review of documentation to ensure that only what is required is incorporated. Third, validation of useability and content at operational evaluation and other testing. Finally, keeping the TMs current through change pages and revisions.

COMPUTER RESOURCES SUPPORT (CRS)

"The facilities hardware, software, documentation, manpower and personnel needed to operate and support embedded computer systems," is known as Computer Resources Support as described in DODINST 5000.2. The areas of CRS which influence Ai the most (embedded training, rapid prototyping etc.,) are covered in other areas of this paper. Thus, the discussion of this area will be minimal. It will suffice to say that as with other elements, CRS should be executed at the minimum level to ensure availabilities near the Ai of the system are maintained. This level of effort is the CRS EIOP. In order to accomplish this, efforts which may assist, include documentation review, rapid prototyping and software maintenance.

Documentation review includes reviewing data definitions, entity relationship diagrams, and bubble charts. The key is to ascertain whether the minimal level of mission functional requirements are met. As in other areas, unneeded functions should be eliminated. Also similar to other elements, a large portion of reaching the EIOP is determined by design. A large portion of system availability is influenced prior to a single line of code ever being written. It is thus important to review the documentation for both adequateness and over kill.

Another effort mentioned was rapid prototyping. Many software coding "errors" result from coding which works correctly, but correctly performs an erroneous or unneeded function. Rapid Prototyping (RP) can catch these interface errors early and be helpful in avoiding both sub and "over optimization" of the CRS EIOP. RP works well because human interface errors can be easily spotted. Since this is done prior to the actual software being coded, costly software revisions can be avoided.

The next area to be discussed is software maintenance.

Software maintenance can result from functional changes, equipment changes, or the discovery of coding or logic mistakes. The key to optimizing this effort is to discover the most efficient revision point based on its criticality. This simply means that a determination of how many and how severe required software changes should be before new software is developed. With today's modular programming concepts and reusable coding, software changes do not always mean total rewriting. Thus an optimal point would involve trading off some improvements in the interim between revisions for more efficient time frames of software improvements.

The final area of CRS is hardware. Optimization in this area involves using standardized equipment when the it can meet equipment mission. The use of standard computer components reduces the cost of developing support for the components since they already are ILS supported. Thus if non-standard components are included in the design where standard components would work a waste in resources results.

PACKAGING, HANDLING, STORAGE, AND TRANSPORTATION (PHS&T)

As described in 5000.2 PHS&T is "the resources, processes, and procedures, design considerations, and methods to ensure that all system equipment and support items are preserved, packaged, handled and transported properly. This includes environmental considerations, equipment preservation requirements for short and long term storage, and transportability."

As with the other elements, the goal is to do the minimal effort in this area which ensures that parts, equipments and systems are delivered undamaged. For clarity purposes the various sub-elements of the PHS&T are as follows:

Packaging

Packaging can have serious consequences on whether or not system availabilities are affected. Packing should be just adequate enough to ensure that parts, components, and the equipment itself are not damaged while handling, storing or transporting. Packaging requirements are entwined with the other elements of PHS&T. An example would be when the component is planned on being shipped. In general, using rail transportation requires sturdier packaging then air or truck. Another example is storage. Open storage requires entirely different packaging then inside climate controlled storage. Thus for this example, the component will be stored indoors and shipped by rail. An example of excess would be to package the item to withstand outside conditions. An example of under optimization would be to package the item to withstand truck transportation when the shipment will be sent by way of rail. Either of the two examples leads to the PHS&T EIOP not being met.

Handling

Packaging and handling go together by means of marking how a package should be handled and what equipment should be used to move the packages around (examples: do not use tongs; this end up; fragile; or do not expose to X-rays). To a large degree the two activities have direct effect on one another. Simply stated: the better something is packaged, the rougher you can handle it and the rougher you handle something the better it needs to be packaged. With this paradox stated, in order to optimize handling, the methods and equipment used should be the minimal required to ensure that system Ao is not compromised. One example is supply methods: JIT would require rapid handling methods since no safety supply is needed. Thus the handling methods chosen would have to meet special JIT driven needs. The key to the optimal point is using no more or no less resources then required..

Storage

Like handling, storage is to a large degree influenced by packaging. In general, the optimal point of storage is the minimal space and type of storage required to avoid part/equipment damage (which hurts system availability).

Transportation

Transportation optimization involves choosing the least cost method of transport which meets mission needs. It also involves ensuring that equipment or systems are transportable. Use of expensive air transportation when rail would do is not justified. Sub-optimization could be the reverse of the above; using rail when air would be required to meet mission needs.

Table 1 below shows the advantages and disadvantages of the different methods of transport. These advantages and disadvantages should be considered as trade off variables when attempting to optimize transportation.

SUPPORT EQUIPMENT (SE)

Support equipment as described in DOD 5000.39 is: "all equipment (mobile or fixed) required to support the operation and maintenance of a material system. This includes associated multi-use end items, ground handling, and maintenance equipment, tools, metrology and calibration equipment, test equipment and automatic test equipment. It also includes the acquisition of logistic support for the support and test equipment itself."

In order to reach the SE EIOP, SE requirements need to be equally matched with the support provided. As with previous elements, system design can have a positive or negative result on the SE EIOP and the overall system availabilities.

MODE TO VARIABLE RATING
(1-5, 5 as best)

MODE	[1]Reliability	Speed	Cost	Equipment Damage/Loss
Water	2	2	5	3
Motor	4	4	3	4
Rail	4	3	4[2]	3
Air	5	5	1	4

Notes

[1]Reliability for this chart means that the shipment arrives on the predetermined time.

[2]Rail is very inexpensive when moving bulk or commodity goods. However, less than car load rates negate some of the cost savings for smaller shipments.

Table 1 - Advantages and Disadvantages to Different Methods of Transport.

When designing equipment, the issue of testability should be considered. The use of built-in-test equipment, automatic test equipment, and standard test equipment can all lead to lower life cycle cost while still meeting testability requirements. The key is to consider these options early and to meet testability needs using the least resources.

Also important in the area of SE, is to maximize the use of standard general purpose test equipment and minimize the use of costly system unique test and support equipment. Again the goal is accomplished in design. If these concerns aren't reflected in the system design, we will have a system which always requires more SE resources than it should have.

Sub-optimal performance in SE is somewhat easier to tackle. Through various analyses, SE functions can be determined. Important functional areas include maintenance and testability. Once these functions are identified, its a matter of ensuring that these functions can be met with the SE provided. If these functions are not met, system Ai will not be maintained.

FACILITIES

DODINST 5000.2 defines facilities as: "the permanent or semi permanent real property assets required to support the material system. This includes the conduct of studies to define types of facilities or facilities improvements, locations, space needs, environmental requirements, and equipment." The discussion concerning facilities will be somewhat brief. It will suffice to say that in order to reach the facilities EIOP, a trade off between new and modified space should be conducted. The most economical space which will meet system needs, without being detrimental to system Ai should be used. Also as with other elements, facility requirements should be considered when designing the system.

DESIGN INTERFACE (DI)

As described in DODINST 5000.2 "the relationship of logistics related design parameters, are expressed in operational terms rather than as inherent values, and specifically relate to system readiness objectives and support costs of the material system." The goal is to let system readiness and the logistic support of the system influence system design.

As mentioned before, this paper discusses ILS planning and LSA. ILS planning includes all of the planning, plan preparation, contract preparation, ILS element plan preparation, ILS meetings, and other efforts involved in logistic planning and ILS execution. These efforts are very costly in both time and dollar resources. Like the other ILS sub-elements, ILS planning has an optimal point in which the resources exerted will ensure equipment Ai is approached using minimal resources. Also as with the sub-elements, if more effort is exerted than required to achieve Ai it is a waste of time and money.

ILS planning is an area which can waste large dollar resources. Often plans and documents are prepared based on checklist and instructions, without understanding the reason for their development. A backward approach should be taken in which system readiness is the ultimate target. All plans and efforts should be based on the maintenance of availabilities. Planning should first focus on influencing design to have the very best practical system availability, and second, support the system once it is designed. ILS planning should also focus on ensuring that support is economically provided. If a plan, meeting, document, etc., does not influence design, or help ensure support, it should not be done. ILS audits, instructions, etc., should be altered to reflect this backward path methodology.

LSA as a sub-element of ILS planning will now be discussed. The key to optimizing LSA is very similar to the optimization of ILS planning. The target is maintaining or improving system Ao. LSA tasks should either improve (through design) the system Ao or should ensure adequate ILS support. If neither of the above goals are accomplished through the execution of an LSA task, the task should not be performed. The EIOP of LSA is reached when the extended effort is just enough to ensure the best practical equipment Ai has been positively affected through LSA influenced design and that the design is supported at minimal effort.

INTERFACE BETWEEN LOGISTICS AND DESIGN

When could one better influence the life cycle costs of a ship than during its design? This means that sparing needs to be closely integrated with equipment selection and ship systems design. Manpower and personnel, maintenance planning, and supply support all depend on the equipment selected and on the spares supplied.

In order to predict the reliability and maintainability (R&M) performance of a new ship, it is necessary to determine and verify the spares, mean logistics delay time, maintenance burden, and the total effect they have on operational availability. The better the support, the closer operational availability (Ao) approaches the inherent availability (Ai). These systems reach a point of diminishing returns after which additional resources slowly drive operational availability closer to inherent availability. How closely a system approaches its inherent RMA performance is a design and management decision. These life cycle decisions can not be made without quantitative predictions of cost, operational and supply system impact.

The Navy has used increasingly sophisticated math and computer models to predict sparing and repair. The NAVSEA TIGER RMA simulation has been used for two decades to design new combatants and auxiliary ships for the Fleet. Increasingly detailed sparing, maintenance, and logistics calculations have been incorporated with each new version of TIGER.

REQUIREMENTS FOR TIGER/RMA ANALYSES

There is broad based need for increased attention to reliability, availability, maintainability, quality, and logistics due to extended service lives, delayed availabilities, and reduced resources both for ship design and overhaul. This need for total ship/system R&M modeling has been recognized by NAVSEA and all levels of DoD. In 1987, OPNAV institutionalized the use of TIGER for operational analysis of ships. [2] NAVSEA reiterated this in 1989 and required TIGER for development and design, determination of operational availability (Ao), sparing, and manning tradeoffs. [3]

The new DoD acquisition instruction 5000.2 [1] requires R&M and the establishment of readiness objectives and thresholds at Milestone I and beyond. A consistent set of objectives and thresholds for readiness, reliability and maintainability must be established by Milestone II. Both technical and operational thresholds should be established for reliability, maintainability, inherent availability and operational availability. This instruction further states that the sensitivity of manpower and other support resource requirements to changes in R&M and utilization rate impact on system readiness and supportability should be analyzed and logistics risk areas identified. The spares investment levels should be related explicitly to readiness and be based on realistic estimates of demand rates and system utilization.

The most efficient way to achieve these requirements is by using the enhanced version of TIGER to assess the total ship, identify the greatest contributors to ship unavailability, and work to alleviate the problem areas by optimally sparing mission critical equipment. The new TIGER does all this, including developing optimized spares lists.

It now becomes imperative to extend the use of these R&M tools to battle group assessments, provide computer visualization for the input and output, and make these programs available to the entire NAVSEA organization including field activities for R&M analysis and shipboard assessment of readiness using data from shipboard equipment condition based monitoring.

HISTORY OF TIGER DEVELOPMENT AND USE

The NAVSEA TIGER R&M computer simulation has been extensively validated and used in the design of every new class of Navy combatant and amphibious ship during the past two decades (see Table 2 for a detailed list of NAVSEA ships analyzed with TIGER). This program is the Navy specified R&M prediction tool for weapon system design [3]. It has been used in making decisions ranging from determining which research and development projects to fund all the way through planning alterations to make for mature ship classes. TIGER has been delivered to over 250 sites at other government facilities, contractors, and friendly foreign nations. The program has been enhanced continually and recent breakthroughs have demonstrated orders of magnitude increases in speed.

The new TIGER computer program has the capability, speed, and precision needed to analyze the R&M and

CLASS TIGER USAGE

AE 26/32	CVV	LSD 41/49
AO 177	DD 963	MCM 1
AOE 1/6	DDG 51	MHC 51
AOR 1	DDG 993	PG 84
ARS 50	FF 1052	PG C/G
CG 16/26	FFG 7	PHM
CG 47	LCAC	SSN 21
CGN 36/42	LHA 1	TAGOS
CV 67 MR	LHD 1	TARC
CVN 70	LPD 4	TRIDENT

Table 2 - TIGER Used to Perform R&M Analyses on New Ship Classes

Concept Formulation
Feasibility Studies
Preliminary Design
Contract Design
Detail Design and Construction
Readiness Based Sparing
Readiness Improvement Program
SHPALTS / MACALTS / ECPs

Table 3 - TIGER is Employed in a Broad Range of Applications

TIGER ADVANCES

- o FY80-90 INCREASED EFFICIENCY 100X
- o FY90/91 FUNDED UNDER PIF
  - NEW ALGORITHMS AND FUNCTIONS
  - WORKSTATION SPEED
  - >1000X PRECISION

Table 4 - Significant Advances Made with TIGER program

logistics performance of total ships down to the Line Replaceable Unit (LRU), but this requires parts level data and takes considerable effort. Typical applications at this time encompass modeling the total ship at the equipment level, determining which are most critical to the operational availability of the hull, mechanical, electrical, and combat systems, then performing Readiness Based Sparing (RBS) optimization for the selected items.

With the enhanced capabilities of TIGER, carrier battle groups and amphibious task forces can now begin to be modeled by considering the ships' redundant supply, communications, and weapons systems. The range of RMA applications is broad and detailed. Table 3 lists areas and involvement from concept formulation through service life extension. R&M plays an important part in each of these particularly preliminary design, contract design, and readiness based sparing because the program follows OPNAV's Availability Centered Inventory Rules (ACIR). [4,5]

ENHANCED VERSION OF TIGER

NAVSEA has completed a major enhancement of the TIGER Reliability, Maintainability, Availability (RMA) computer simulation program. (See Table 4.) The current changes increase the program's speed, precision, ease of use, and productivity. This enables Department of Defense reliability engineers to perform R&M analyses of very complex systems and comply with the requirements of DoDINST 5000.2, Defense Acquisition Management Policies and Procedures. We envision that all of DoD and numerous other government agencies will benefit from this work.

While the TIGER program has undergone a major enhancement approximately every two years since its inception 20 years ago, this one is dramatic. TIGER RMA simulations of total ships previously required about an hour of processing time on today's mini-computers. The new TIGER Version 9 will require only seconds to perform the same analysis (see Figure 1). The enhanced TIGER performs these assessments with the increased precision (six significant figures) required for assessment of battle groups and equipment sensitivity tradeoffs. This translates to on-line assessments now taking seconds but performing computations that would have previously taken more than a full year. It also incorporates the capability to design and optimize system spares for operational availability based on three continuous parameters such as cost, weight, and logistics delay time.

As a result of NAVSEA development efforts started with FY 90/91 Productivity Investment Funds (PIF), the enhanced TIGER computer program is able to perform R&M assessments of total ships and battle groups millions of times faster than previous versions of the program. Significant design tradeoffs, including Readiness Based Spares (RBS) optimization, will be possible on NAVSEA CAD-2 workstations running the X Windows System (X11: FIPS 158) environment.

Beta Site test copies of TIGER (version 9) were distributed to NAVSEACENLANT, NAVSEALOGCEN, and NAVSSES personnel for evaluation. They assisted in finalizing the input and user friendly features of TIGER. A user questionnaire was be sent out in January to over 100 government and contractor sites which have requested TIGER in the past. The survey documents the impact this high speed workstation program will have on their operations and identifies which locations desire the new program being distributed by SEA 5121.

FEATURES, CAPABILITIES, ADVANCES, AND OPTIMIZATION

The new capabilities and characteristics (see Figure 2 for overview) of TIGER are:

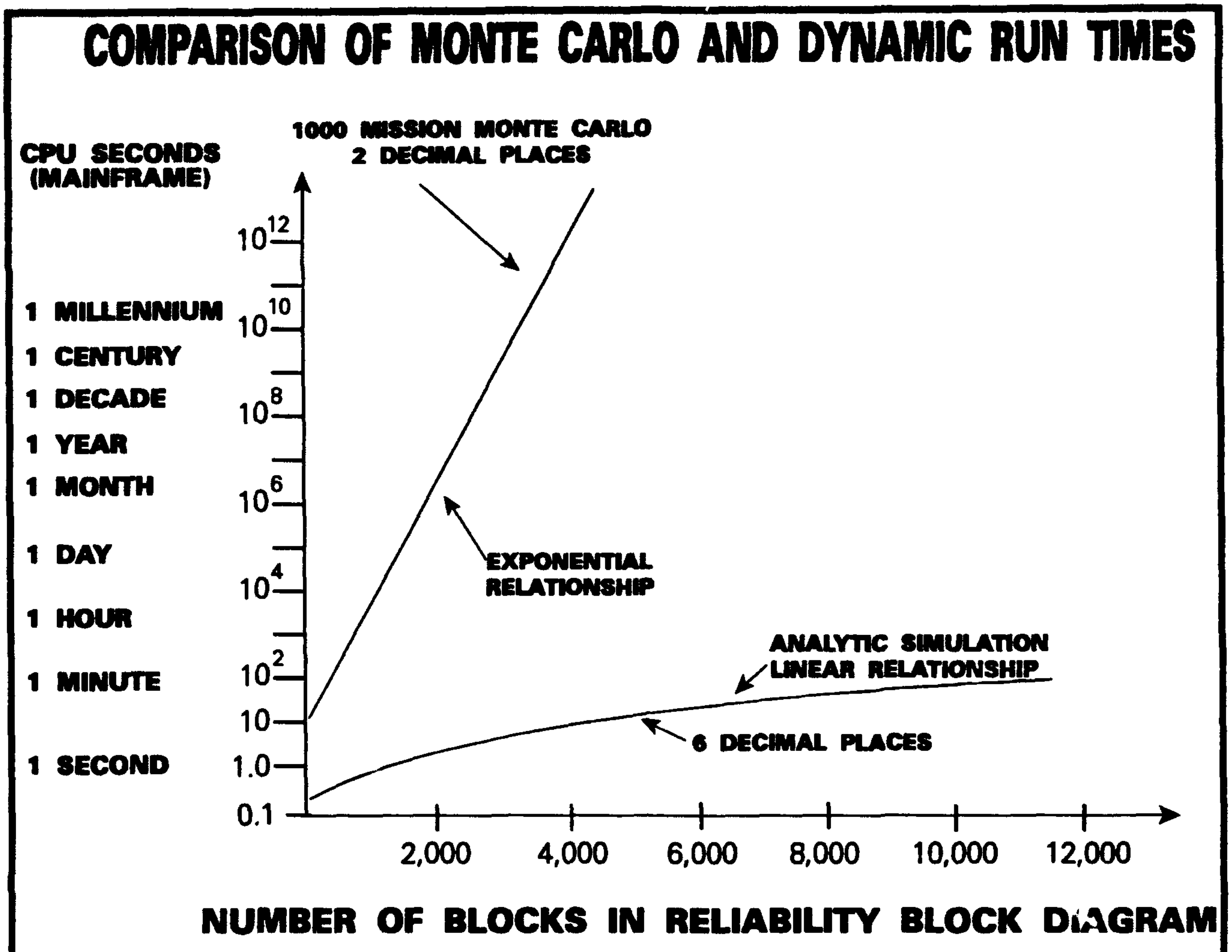


Figure 1 - TIGER Runs made with Monte Carlo and Analytic Techniques

TIGER now calculates reliability and availability performance based on numerical solution of the failure and repair transition rate differential equations.

TIGER follows the Availability Centered Inventory Rules for spares determination. It can now be used to optimize reliability and operational availability, functional design, and spares by cost, weight, power consumption, logistics delay, etc. Repair shop limitations are included to help assess the maintenance personnel aspects of the design.

TIGER incorporates the top down functional/reliability block diagram approach to speed design implementation. The new input structure is based on operational, equipment, and logistics areas of expertise.

The computer program is written for transportability and is being delivered for use on mini computer workstations and 32 bit personal computers with math coprocessors.

An input file translation program is included so that TIGER 8.21 input files can be formatted to run with version 9. This enables present users to upgrade previous work without the expense of recoding their reliability models.

TIGER can be redimensioned to run very large R&M models on micro, mini, and mainframe computers using the TIGER RESIZER Program.

The new TIGER CUB, an interactive file preparation program, is included to provide ease of input to the TIGER RMA simulation.

The TIGER Users Manual is delivered in an ASCII text format with the computer program. Print on demand, laser copies can made from this file.

PROGRAM STRUCTURE

The input structure for TIGER 9 has significantly changed from that of the previous versions. An object oriented philosophy was used to design this structure in order to make it easier to use by being similar to the way engineers, naval architects, and logisticians prepare their design information. All input falls within five grouped areas (see Figure 3 for an overview). Group 1 encompasses Run Control, the availability or reliability objectives, mission time line, etc. System and function structure is developed in Group 2 while

TIGER 9 FEATURES

SYSTEM STRUCTURE AND OPERATION

BLOCKS BY FUNCTION
REDUNDANCY
MULTIPLE INDENTURE LEVELS IN SYSTEM
MULTIPLE BLOCKS FOR AN EQUIPMENT NUMBER
OPERATING RULES
MULTIPLE PHASE MISSIONS
ALLOWABLE DOWNTIME

OBJECTIVE FUNCTION/FIGURE OF MERIT

MISSION AND STEADY STATE AVAILABILITY
MISSION RELIABILITY
SPARES OPTIMIZATION*
DESIGN OPTIMIZATION*
RMA IMPROVEMENT CANDIDATES*

EQUIPMENT CHARACTERISTICS

MULTIPLE INDENTURE LEVELS IN EQUIPMENT*
MULTIPLE PART REPLACEMENT REPAIR*
MTBF/BRF DESTINCTION*
EXPENDABLES

SUPPLY SUPPORT CHARACTERISTICS

COMMONALITY OF PARTS*
RESUPPLY
FLSIP/MOD FLSIP SPARING
DEMAND RESPONSE (EQUIPMENT LEVEL)

***NEW TIGER FEATURES**

Figure 2 - Features of the New Version of TIGER

equipment characteristics are specifically identified in Group 3. The logistics considerations of sparing support and repair shops are quantified in Groups 4 and 5 respectively. In this way the model can be built up by individuals working separately in their specialties to contribute to the whole.

CONTINUOUS PROCESS IMPROVEMENT OF TIGER RMA PROGRAM

In the spirit of Total Quality Management - Continuous Process Improvement (TQM), the refinement of TIGER RMA modeling does not stop. Work is presently underway to develop an interactive user interface to the program which handles the development of reliability block diagrams (RBDs), input, run control, and output analysis. The RBD program will permit the designer to interactively develop Reliability and Maintainability (R&M) models from functional block diagrams. It is being developed as a transportable, workstation based, interface program capable of interactive construction and graphical display of reliability block diagrams (RBDs).

The program will employ Artificial Intelligence (AI) and advanced windowing techniques to establish interfaces which make it easy for the designer to develop and assess RMA tradeoffs. It will contain rules for identifying equipment which are best suited to implemention of diagnostic expert systems for failure analysis, spares identification, and corrective maintenance.

This interactive program will operate with the X Window System in the UNIX, VMS, and mini computer environments. Windows will be used to run the enhanced TIGER family of RMA programs on 32 bit personal computers.

Multi-Echelon TIGER Analysis will extend TIGER to sparing analysis at the organizational, intermediate, and depot levels. It will be used to assess the complexities of multi-echelon positioning and the resupply network.

An Output Visualization program that could be developed as a post processor to ease the designer's analytical burden by providing graphical visualization of the TIGER program's output data is being proposed. This program would use expert systems to provide assistance in interpreting the output. The program would process large amounts of numerical data and display it in highly intuitive 2D and 3D graphs within the evolving X Window System and the Windows environment on 32 bit computers.

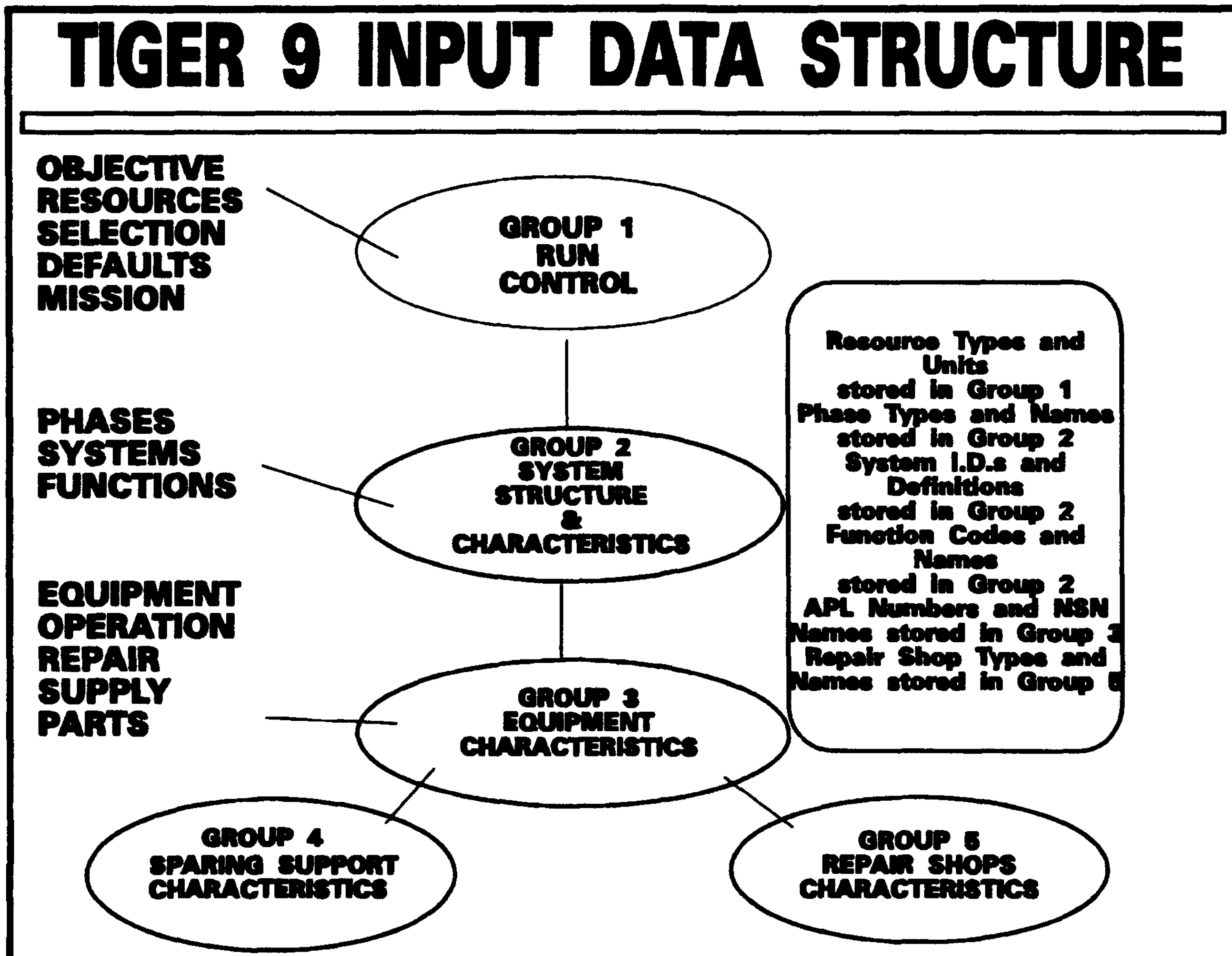


Figure 3 - TIGER 9 Input Data Structure

INTERFACES TO THE DESIGN PROCESS

We are working to integrate the enhanced speed TIGER Computer Program Family into the Computer Supported Design (CSD) software to provide an on-line, workstation R&M package and provide these tools to the entire DoD community.

Based upon DoD wide needs for computer programs to support the entire community, we will seek OPNAV and DoD certification [5] of the enhanced TIGER family for the widest possible distribution.

Current efforts by SEA 5121 focus on interactive construction and display of Reliability Block Diagrams (RBDs) required as input to the TIGER program. This development incorporates use of the X Window system in the UNIX, VMS, and DOS environments. Computer supported design division (CSD) tasks will focus on demonstration of the integrated TIGER/RBD family of programs on machines with these operating systems. Future tasks would include demonstration of the Multi-echelon sparing optimization version of TIGER in the CSD design process on CAD 2 machines.

RESULTS OF TIGER VERIFY THEORY

The enhanced speed, workstation version of the NAVSEA TIGER Reliability, Maintainability, and Availability (RMA) computer program has been developed. It performs the customary TIGER RMA analyses orders of magnitude faster that the older, Monte Carlo versions of the TIGER simulation. Increased speed and precision allow TIGER to be used in the CAD 2 workstation environment and support detailed sensitivity and tradeoff studies from early design through the SHIPALT cycle.

We can now perform the previously impossible task of assessing the impact on total ship availability caused by changes in sparing, logistics, maintenance philosophies, equipment reliability and operational scenarios while working in an on-line workstation environment. This truly helps us in finding the inherent optimal point where operational availability approaches inherent availability at an acceptable cost.

CONCLUSIONS

This paper discussed an idea of an optimal integrated logistic support point described through optimization of individual element IOPs. The key issue is to first consider ILS and reliability concerns in system/equipment design. Second, after design, provide logistics support at the minimum level necessary to maintain system/equipment Ai. When this is accomplished, you have reached the IOP.

References

[1] DODINST 5000.2, DEFENSE ACQUISITION MANAGEMENT POLICIES AND PROCEDURES, 23 February 1991.

[2] OPNAVINST 3000.12, OPERATIONAL AVAILABILITY OF EQUIPMENTS AND WEAPONS SYSTEMS, 29 December 1987.

[3] NAVSEAINST 3900.2B, RELIABILITY AND MAINTAINABILITY (R&M) PROGRAM, 10 October 1989.

[4] CNO letter Ser 412/394582 of 16 March 1981, Subj: Shipboard Availability Centered Inventory Rules; approval of.

[5] OPNAVINST 4441.12B, RETAIL SUPPLY SUPPORT OF NAVAL ACTIVITIES AND OPERATING FORCES, 25 May 1983.

The Evolution of Patrol Boat Coastal From Boat To Ship

Dennis J. Doyle
Assistant Program Manager
and
Joseph C. Mayer
Project Engineer
Combat Craft, Service Craft, and Amphibian
Acquisition Program Office
(SEA PMS3008)
Naval Sea Systems Command

May 1992

Abstract

The Patrol Boat Coastal, (PBC) had its origins in an early requirement for a craft that was to support operations of Naval Special Warfare forces. This requirement was expanded to include capabilities that were defined as a result of early Persian Gulf experiences with the Mk III patrol boats. These combined requirements were stated in the PBC Letter Operational Requirement [1] which also directed that PBC be a Non-Developmental Item (NDI) procurement.

The acquisition process for the PBC was a two-step best value procurement which allowed each boat builder to propose his own commercial or foreign military design based on a Top Level Specification (TLS) and a Circular Of Requirements (COR). A broad range of craft were proposed with the successful offeror proposing a 170 foot craft in the 315 ton (full load) range.

The size of the craft led the Chief of Naval Operations (CNO) to ask, "Why can't I commission them?" After a prompt review of the implications of commissioning, the CNO recommended to the Secretary of the Navy that the PBC be commissioned and that office concurred. [2]

This paper will address some of the impacts of that decision, both those known at the time and some discovered since then. Some of the areas where differences exist between boats and ships are: Names, Hull Numbers, Specifications, Unit Identification Codes (UIC), Models and Mock-ups, Testing, Certification, Manning, Maintenance and Launch. Our paper will address these differences and their impact on the acquisition of the Patrol Coastal (PC, formerly the PBC).

INTRODUCTION

Patrol Boat Coastal

In January 1991 the CNO asked during a briefing, why can't I commission these 170' PBC's? Thus began the transmogrification of Patrol Boat Coastal (PBC) to Patrol Coastal (PC-1) Class ships, the Navy's newest class of ships, and no one knew exactly what was involved. Some thought, "all you need is a bottle of champagne to whack on the bow". Others, like COMNAVSEA saw a more significant effort and on 1 February, 1991 recommended to OPNAV that the commissioning decision be delayed [3]. This paper attempts to document some of the differences between a boat and a ship and hopefully shed some light on the decisions that must be carefully made for those craft, like PC, that are on that blurred line between a large boat and a small ship. With the challenge to the Navy to down size over the next several years there will be a great need for all ships and boats to take on more tasks. As we load more functions and equipment on larger craft, based somewhat on lessons learned in the Persian Gulf, other craft may creep up into this blurred region of big boat or small ship.

This paper was written in order to document our findings and establish the beginnings of a data base on the requirement differences between a big boat and a small ship. We hope it will be of benefit to future Program Managers of programs that end up being small ships by providing some insight into the waves that lie ahead.

Characteristics

PC-1 Class ship characteristics are as follows:

Length	170 ft
Beam	25 ft
Draft	7.8 ft
Displacement	315 Tons (Full Load)
Fuel Capacity	11,000 gallons
Propulsion	4 Paxman diesels (3350 BHP each)
Generators	2 Caterpillar (155 KW each)
Speed	35 Knots
Endurance	10 days

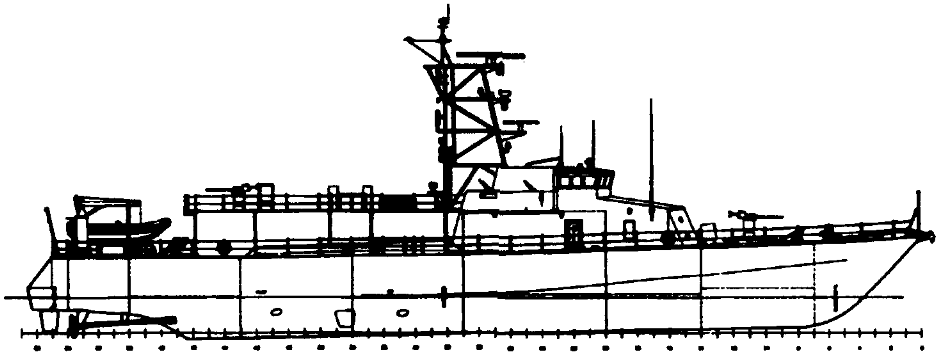


Figure 1 - Patrol Coastal (PC -1) Class

Other:

- Semi displacement all welded steel hull with welded aluminum superstructure.
- Communications equipment (HF voice, UHF SATCOM, VHF, VHF FM, Marine Band, IFF, secure data transmission). Sensors (Surface search and navigation radars, IR surveillance, ESM).
- Navigation Systems (LORAN-C, GPS, Gyrocompass, Fathometer, Sonar).
- Complement: 4 Officers, 1 Chief Petty Officer, 23 Enlisted
- Accommodations: For the above plus one more chief, two more enlisted and a Special Operations Force (SOF) detachment of 9. (See Figure 1)

Early design concepts

The requirement for the PC program has its origins in programs that began in the mid 80's, under the names Special Warfare Craft Coastal (SWCC) and Patrol Craft Coastal (PCC). Although both PCC and SWCC were very similar, they did not have identical requirements. However, the PCC and the SWCC were similar enough that eventually, the CNO decided that they should be combined into one program. Combining these programs offered advantages such as lower procurement costs because of the larger procurement quantity, as well as improved supportability and maintainability. The combined program became known as Patrol Boat Coastal (PBC).

The PBC requirements which evolved from the merger of the SWCC and PCC including range, endurance, weapons, seakeeping and speed required offerors to propose designs which were significantly larger than the existing special warfare boats. Naval Sea Combat System Engineering Station (NSCSES), Combatant Craft Engineering Department developed initial PBC design concepts which indicated the minimum size monohull would be approximately 140 ft [120 ft if a Surface Effect Ship (SES) was proposed]. The feasibility designs indicated that the monohull would be weight critical and topside arrangements would be cramped at best. The SES design, still weight critical, showed much more flexibility in topside arrangements because of its larger beam.

In order to minimize development costs and avoid the time required to develop a prototype design the CNO directed [1] an Non-Developmental Item (NDI) procurement.

PBC/PC Acquisition Process

In view of cost and time constraints the PBC Operational *Requirement identified* the basic craft as a NDI. This Operational Requirement Letter approved the baseline PBC for Full Scale Development, a DOD Milestone II Decision. Additionally, the Operational Requirement identified several craft improvements that were to be developed concurrently as Pre-Planned Product Improvements.

A Non-Developmental Item procurement is intended to be a cost effective approach to meeting the program requirements. The goal is to obtain an already developed product, that with minimal modification, will suit the application. In order to ensure that we procured an existing product, that when modified, best suited the Operational Requirements, the Navy decided on a 2 step, best value procurement process [4].

First the Navy developed a Circular Of Requirements (COR) [5] and a Top Level Specification (TLS) [6]. The COR identified the performance characteristics for the PBC, such as reliability parameters, maximum speed and maximum draft and identified space and weight reservations for the Pre-Planned Product Improvements. The COR also identified the craft's missions so that offerors could modify their current products to suit the PBC's mission requirements.

The Top Level Specification (TLS) provided basic design criteria that identified components and requirements to be incorporated into the contractor's specifications. The TLS identified things such as material requirements for piping systems, minimally acceptable components such as the craft's rigid inflatable boat and general contract specification requirements. In keeping with the NDI approach the TLS did not approach the specificity of a typical shipbuilding specification.

The first step in the contracting process required each offeror to submit their technical proposal which described the craft they had designed or modified to meet the requirements identified in the COR and TLS. Each offeror was also required to provide a proposed contract specification which included requirements identified in the TLS. The Navy evaluated each offerors technical proposal to ensure that the offeror met the requirements, and gave each proposal a numeric score.

The second step in the contracting process was to request price proposals from offerors that met the minimum requirements with an acceptable design. The Navy then awarded a contract for a Coastal Patrol Boat to the offeror whose technical score when combined with the proposed price demonstrated the best value to the Navy.

DECISION TO COMMISSION

In the study to respond to the CNO's question several areas were reviewed. These included the legal implications, the ship force levels, historical precedence, the administrative requirements and the funding considerations as best as they could be determined within the time allotted in order to provide a timely response. What follows is a summary of the response that was prepared by the OPNAV staff for PBC.

The legal implications basically boiled down to two minor areas. First of all, a US Navy ship must be built in the USA. Second, if a ship was under armed forces control it was either a Warship if it bore external markings and was under the command of a Commanding Officer, or it was an Auxiliary. Because both are used only for Government non commercial service both have, similar to many Navy vessels; sovereign immunity which includes immunity from arrest and search, exemption from foreign taxes and regulation, and exclusive control over passengers and crew. However, none of this is impacted by commissioning because commissioned status is not part of any international statute. No legal guidelines were found that would relate size, manning or other factors to the decision to commission.

With regard to force levels, there are two categories in the Ship and Aircraft Summary Data Tables (SASDAT). They are Total Ship Battle Force (TSBF) and Local Defense and Miscellaneous Support Forces (LDMSF). The often quoted "600 ship" Navy, or now "450 Ship" Navy is a measure of the Total Ship Battle Force. These are the fully deployable commissioned ships of the US Navy. The PC, with its primary mission of coastal patrol and interdiction and somewhat more limited range, is appropriately in the Local Defence and Miscellaneous Support Forces category. Therefore its commissioning will not impact the "450 Ship" Navy.

A historical review of commissioned ships also failed to reveal any established guidelines as to length, crew, armament or mission that would determine whether or not a vessel was commissioned.

A review of the administrative requirements however did show that a far greater responsibility fell on a Commanding Officer than did on a craft Officer-In-Charge (OIC). While it is envisioned that many non-operational program requirements would be shifted to the immediate unit commander this may yet show to be the Achilles Heel of the decision to commission the PC.

The funding impacts at the time of the recommendation to commission were thought to be the cost of the ceremony, that "bottle of champagne", and the cost of modifying the contract to get a ship name, hull number, ship plaque and a commissioning pennant put aboard. NAVSEA expressed a concern that there would be hidden costs and hence COMNAVSEA's recommendation to defer [3]. OPNAV responded with an agreement to waive all items imposed as a result of the decision to commission [7]. We are only now beginning to be able to quantify these impacts.

What follows is a list of some areas impacted by the commissioning decision and a discussion of the impacts we know of today. Our aim is to record these as a lessons learned in the event a future program is faced with a similar commissioning decision. This paper may help them to quantify the impact of commissioning.

Vessel Names

Boats and craft are not normally named. However, Naval Special Warfare, the PC end-user, has a history of naming classes of combatant craft. Examples being the 36 foot Special Warfare Craft Light (SWCL) and the 65 foot Patrol Boat (PB) Mk III, otherwise known as SEAFOX and SEASPECTRE respectively.

Commissioned ships on the other hand are named. Names are assigned by the Secretary of the Navy via SECNAV Note. The process by which ships are named begins with the Congress budgeting money for a ship. Congress authorizes and appropriates Shipbuilding, Conversion Navy (SCN) funds for the ship. The SCN funds become the trigger that gets SECNAV to designate hull markings and the Naval Historian to make recommendations as to the ships names. For a new class of ships the historian may research ships with similar characteristics and missions, in order to recommend the best name. The Historian then proposes a roster of names to the Secretary, who has final selection authority.

The PC, being a Special Warfare craft and not a ship may have had a class name like the SEAFOX and SEASPECTRE but because it was not in the budget as a ship it did not trigger the "naming process". In the process of researching for the CNO the impact of commissioning the PBC, the Naval historian was asked to make a recommendation for a class name for the PBC. While recommendations for hull names were made, these did not constitute the official roster of recommended names. As the initial drafts of this paper were prepared, the PC's did not have names. Once the Secretary of the Navy agreed to commission PC's [2], he then was requested to designate a new class of ships called "PBC". That proposal was rejected and the designation "PC" was selected [8] with the class beginning at hull number 1.

Following that discussion, the Naval historian recommended eight names with five alternates. The Secretary of the Navy has recently assigned [9] the following names for PC's: PC-1, Cyclone, PC-2, Tempest, PC-3, Hurricane, PC-4, Monsoon, PC-5, Typhoon, PC-6, Sirocco, PC-7, Squall, and PC-8, Zephyr. PC's 9 through 13 have yet to be assigned names.

The individual ship's are named at a Christening ceremony with a certain amount of pomp and celebration. All of this takes planning and time to staff recommendations for selection of sponsors. For most ship programs this is initiated when the ship is programmed in the budget. Because of the late decision to commission PC, a lot of last minute effort has been required. While not key to its combat capability, this effort still requires early attention.

Hull Numbers

NAVSEA PMS300 assigns hull numbers for all boats and craft. This hull number usually consists of four components; Length, boat/craft type, fiscal year, and hull number. For example, the first 36 foot Landing Craft Personnel, Light (LCPL) awarded in Fiscal year 1992 would have 36PL9201 as a hull number.

The Secretary of the Navy designates ship classification and type designators (ie. CVN for Multi-purpose Aircraft Carrier Nuclear-Propulsion). Type designators are assigned and listed in Secretary of the Navy Instruction [8]. NAVSEA maintains a record of hull numbers for each type designator, after reviewing the history of assigned numbers under the ships type designator, NAVSEA assigns the ships hull number [10] which becomes a part of the hull markings.

PC-1 had her keel laid (22 June 1991) less than three weeks after the decision to commission (5 June 1991) and SECNAV had not assigned the hull markings for the ship class. Prior to the commissioning decision, the PC-1 hull number was "170PBC9001" as assigned by NAVSEA PMS300. The program office knowing that the current hull numbers would be incorrect had to anticipate the SECNAV assigned hull markings. This resulted in a change from "170PBC9001" to "PBC-1" and PC-1 had "PBC-1" stamped in her keel during her keel laying ceremony on 22 June 1991. Since several other PC's were under construction prior to the commissioning decision, many structural components for PC's 1 through 3 have various numbers and identifiers marked in their frames, deck plates and shell plates in order to identify one ship's components from another's. A contract modification was required to change future hull numbers, and to correct drawing and technical manual titles.

Further, the Fleet Introduction Team for PC Class ships, was identified as "PBC FIT NEW ORLEANS" for quite some time after the commissioning decision.

Specifications

Boats and craft are procured using several different types of specifications such as: Boat/Craft Specification, Circular Of Requirements (COR), Commercial Specifications, and Top Level Specifications (TLS). When a specification is generated for the prospective solicitation, it begins with the Standard specification for building boats and craft (Standard Spec) [11]. The Standard Spec is tailored to meet the unique mission requirements of the boat or craft. The Standard Spec was developed by NAVSEA PMS300 and NSCSES and is the small boat version of the Navy's General Specifications for Ships Of The US Navy (GENSPECS) [12].

Ship specifications are generated by NAVSEA using GENSPECS as a baseline. GENSPECS are tailored to meet the specific mission requirements of the ship. GENSPECS was developed by NAVSEA in order to provide basic ship requirements and set standards for US Navy ships.

The PC was procured as a Non-Developmental Item, and the program office decided to use a TLS and a COR for procurement. Since commissioning was not even under discussion at the time the TLS was being prepared, GENSPECS did not come into play and the TLS was a derivative of the Standard Spec. These documents identified minimally acceptable standards which, each offerors proposal was required to meet. Each offeror was required to generate a specification for the PBC, which upon contract award, became the contract specification. Under this process, the PC's are tailored to commercial standards such as United States Coast Guard, American Bureau of Shipping (ABS) and Institute of Electrical/Electronic Engineers (IEEE) standards. This will result in a challenging effort to trial and accept PC for Naval service. The clear "checklist" of GENSPECS does not exist for PC and some subjective judgement will be required as to the acceptability of the PC design.

Unit Identification Code (UIC)

A Unit Identification Code (UIC) identifies all DOD activities through a 6 digit alphanumeric code. Navy activities' codes begin with a letter "N" followed by a 5 digit identifier. NAVSEA's, you may all recognize, is N00024. One of the many uses of the UIC is to identify funds for a particular ship or field activity, for example, outfitting funds are identified by UIC. There are other uses of the UIC, such as Configuration Management, that are important throughout the units life cycle but these are not addressed here.

In general, boats and craft don't get individual UICs. Each will eventually use the UIC of the organization or command to which it is assigned. Ship's boats will use the ship's UIC and boats assigned to shore activities will use the shore activity UIC. However, before a boat is assigned to a command, the Navy assigns a generic UIC to the particular class of boats in order to identify outfitting funds for the class. NAVSEA orders outfitting material using funds identified under the generic UIC and has the material shipped to the boatbuilder.

Ships on the other hand, will be assigned their own UIC. Similar to the boat and craft procedures, NAVSEA orders parts using funds identified under a UIC, but unlike boats and craft, each ship will have a different UIC. This ensures that outfitting materials are properly identified and accounted to each ship.

The PBC, as a boat, was assigned a generic UIC for the class under which outfitting funds were identified. Eventually each PC ship was assigned a separate UIC, however outfitting funds could not be moved from the generic UIC to each ships UIC. To order outfitting materials, NAVSEA must order outfitting material under the generic UIC for the class, then ship the materials under each individual ships UIC to the shipbuilder. Special provisions had to be made because the PC's unique genesis from a boat to a ship that resulted working with both the generic UIC for the class and each PC's individual UIC for outfitting material.

This is not only one more example of the differences between ships and boats, but it is also an area where early attention may prevent establishment of the generic UIC or perhaps allow correction before the initial material orders are debited to the generic account.

Models and Mockups

Boats and craft do not require a review of models and mock-ups and this type of review is not normally performed. In many cases, prototypes or first articles of boats or craft may be built which undergo first article testing. These tests can result in configuration changes to the prototype or first article, which are then reflected in the follow-on craft.

Ships are generally required to have a review of models and mock-ups. Spaces typically selected for this review are the Combat Information Center, Communications space, Engine Operating Space, and bridge arrangements. For PC, a CNO team reviewed and approved these arrangements to ensure that they are functionally adequate to support the operations of the ship.

Fortunately, the PC had a contract requirement for the winning contractor to present models and mock-ups for Navy review. This requirement resulted from the NDI nature of the program and the fact that the Navy had not done a contract design package for these spaces. It was decided to have the contract requirement for a Navy review made into a CNO review in order to get operator approval for these key command and control spaces.

This review resulted in one of our largest Engineering Change Proposals (ECP) to date. This is attributed to the fact that the models and mock-ups review team looked at the craft from a ship handling, command and control viewpoint rather than a boat viewpoint. The concept that "Ships are conned" was prevalent during this review, while the PC was designed to the concept that a boat is driven.

Testing

Boats and craft are tested in many different methods depending on the procurement method used and the boats mission requirements. Some boats are tested using prototypes or first article testing, to ensure the boat meets it's mission requirement and some are tested in Builders and Acceptance Trials. For combatant craft, many times the Commander of the Operational Test and Evaluation Force will perform operational tests. For craft which are tested in Builders Trials and Acceptance Trials, the trials team normally consists of NAVSEA PMS300, NSCSES and SUPSHIP (or DCMC) personnel, aided by other field activities as required.

Ships are required to go through very formal testing program starting with Builders Trials and Acceptance Trials. The Builders Trial team generally is made up of SUPSHIP representatives supplemented with additional expertise as required. Acceptance Trials are performed under the purview of the Board of Inspection and Survey. After delivery, the ship is typically tested in accordance with the total ship test program which may include EMI and shock testing, magnetic signature survey, structural test firing of weapons, and other tests. Final contract trials are held just prior to the ships Post Shakedown Availability. Additionally, COMOPTEVFOR performs Operational Tests on a ships weapon systems and Follow on Test and Evaluation on the ship itself.

The PC will undergo Builders Trials and Acceptance Trials as a typical ship. However, the PC was not built to GENSPECS which is typically the bible for these inspections. While CNO has advised [7] that they will waiver those items beyond the ships specification with the exception of mission critical and safety items, it remains to be seen how well this process will work. Avoiding the possibility that the PC would be built to one set of standards, yet tested to another standard was a primary concern of NAVSEA [3] and the program office during discussions that led to the decision to commission.

Certification

Boats and craft have very few certification requirements compared to ships. Boat and craft certification requirements include things such as compatibility with a davit and certification for air transport. Combatant craft also require weapons certifications. Operators must be trained, but certification for lighting off the engines is not required and On-The-Job training at the squadron can be a significant part of the training.

Ships have more stringent certification requirements, starting with a Light Off Exam (LOE) which certifies that the crew is adequately trained to run the propulsion plant and other ship systems. The crew is not authorized to light off the plant prior to passing the LOE and therefore On-The-Job training is not an acceptable approach to training. Other ships certification requirements include, but are not limited to the following: Electro-Magnetic Interference (EMI) survey and certification, Shock, Weapons, radiation survey, magnetic survey, depending on the requirements imposed by the ship's Operational Requirement document.

The PC, will be certified through an LOE similar to that of a ship. Because the PC is designed to tailored commercial standards, certification requirements not directly associated with safety or the PC's mission requirements, are not invoked. For example, the ship certifications identified above are not required for commercial ships, so the PC will be tested to the certifications identified in the Operational Requirement.

Getting this agreement up front with OPNAV is key to avoiding problems later. While agreement was reached with regard to Acceptance Trials is was not clearly stated that this philosophy was to be followed for LOE. The OPNAV letter stated PC would have "LOE & OPPE (like) exams". This has evolved into a formal LOE for PC-1 and unlike AT & FCT there is no established waiver process for LOE. The full impact may not be known until this summer when PC-1 undergoes LOE.

Manning

Boats and Craft are not normally duty stations and do not have Navy personnel assigned to them. Maintenance personnel and operators are usually assigned to the boat or craft's parent command. The various personnel administrative requirements are also supported by the parent command. For example, under Naval Special Warfare, individuals are assigned to a Special Boat Unit. The Special Boat Unit Commanding Officer designates the personnel as crewmembers of a particular boat or craft. This flexibility allows the Unit Commanding Officer to form a crew with the best mixture of background and experience. The crew is then required to complete standard predeployment training prior to deployment, during which time, significant on-the-job training can occur. This is particularly important for a crew that is relatively small in number.

Ships are permanent duty stations and have personnel assigned directly to them. All operators and maintenance personnel are assigned to the ship on a full time basis. Administrative functions are also handled by the Commanding Officer and ships force. This has a significant impact on the training and the need to assure that people are fully qualified at the time they arrive aboard ship. PC training plans had to be regenerated to reflect this significant change in approach to training.

The PC's will have personnel assigned just like any ship, with the exception that, much of the maintenance will be performed by a shore based Maintenance Support Team (MST). Each Maintenance Support Team will consist of 15 personnel and will support 2 PC's. In a way these Maintenance Support Team personnel will take the place of ship's personnel for the maintenance functions but will not come under the direct command of the ship's Commanding Officer. An approach of this sort is used for the PHM with all personnel reporting to the squadron commodore. The PC's Maintenance Support Team however is much smaller than the PHM support squadron and is currently assigned on a 2 ship basis. Time will tell how well this arrangement will work in the special warfare environment. Because of the small size of the ships force, the Commanding Officer will have to be assisted with administrative functions by the Special Boat Squadrons.

Maintenance

Boats and craft are maintained by their operational command. In addition to providing personnel, the command provides funding and spare parts support. Very little maintenance is performed when the boat or craft is underway. There is little room to carry spare parts and tools for maintenance purposes while the boat or craft is underway.

Ships on the other hand will carry spare parts, tools and test equipment in order to perform maintenance while underway. Ships receive funds through the Fleet Commander In Chief and order their own spare parts. Ship systems are designed such maintenance can be performed while the ship is at sea. For example, a ships firemain will have isolation valves that allow the crew to repair or service a pipe or valve without shutting down the firemain.

The PC, like a boat or craft has very little room to carry spare parts, tools, and test equipment. Spare parts are limited to mission critical spares. Most of the planned maintenance will be performed with the assistance of the Maintenance Support Team while the PC is in port. Systems such as the firemain are isolated for damage control and safety, with isolation valves minimized for weight and performance. This approach recognized that valve maintenance would not be done at sea.

This example highlights the fact that in any effort to add certain GENSPECS requirements into an NDI contract or a large boat contract as was done with PC, it is necessary to carefully select the portions of those requirements to be invoked. Firemains are considered to be a safety issue and PC firemains were upgraded by contract modification. However, all GENSPECS firemain requirements were not safety related and a careful tailoring of the modification was necessary.

Launch

Most boats and craft are launched via a crane, davit or trailer. In many cases, boats are delivered with lifting slings so that they can be launched and recovered for storage and maintenance.

Ships are launched from the construction ways, or a graving dock. For maintenance, the ship is drydocked. Apparently, as a result of what is typically done, a comment was made to the effect that Navy instructions prohibit the lifting of a ship with a crane.

The PC's are launched using a crane. Once the decision to commission was made, the prohibition on the crane lifting of a Navy ship, if there was one, would have to be waived.

Because of the uncertainty of many of the other items noted above, the Program Office spent a good deal of effort trying to track down the source of this prohibition. No documented prohibition was found and PC-1 was crane launched on 01 February 1992 and PC-2 on 04 April 1992. This is an example of an effort we hope a future Program Office can avoid by the documentation of our experience.

Summary

The CNO has demonstrated through the PBC/PC program that a boat or craft can be commissioned as a ship. However, as we have shown, there is a lot more to commissioning a large boat than "a bottle of champagne". We have pointed out some significant differences between a ship and a boat that must be identified and addressed as early as possible when a commissioning decision is envisioned. Our list of differences is by no means complete. At the time of this writing, the first PC was under construction and the Navy was still discovering more differences between a ship and a boat.

With an expected down sizing of the Navy and shrinking defence budgets, it is very possible that the Navy will turn to smaller ships in the future. Smaller ships will share in the challenge to identify the differences between ships and boats that fall on that blurred line between a small ship and a large boat. We hope that significant lessons can be learned through the experiences of the PC program.

REFERENCES

[1]. Operational Requirements, Letter OR #238-03-88 of 12 Dec 1988

[2]. SECNAV Decision dtd 5 Jun 91

[3]. NAVSEA Memo 9000 OPR 93 Ser 00/0138 dtd 1 Feb 91

[4]. Coastal Patrol Boat (PBC) Acquisition Plan, NAVSEA #89-009 of 13 Jan 1989

[5]. Circular Of Requirements (COR), Coastal Patrol Boat (PBC) of 10 Feb 89

[6]. NAVSEA T9PB0-AA-SBS-010, Top Level Specification For Coastal Patrol Boat (PBC) of 28 Feb 89

[7]. CNO ltr 3030 Ser 03/1U588917 dtd 21 May 91

[8]. SECNAVINST 5030.1K CH-3, OP-802K1 dtd 25 Jul 91

[9]. SECNAVNOTE 5030, OP-09BE dtd 30 Oct 91

[10]. NAVSEA ltr 5030 OPR 0342D/0101 Ser 03/0118 dtd 29 Jul 91

[11]. NAVSEA 0902-LP-041-2010, Standard Specification For U.S. Navy Craft

[12]. General Specification For Ships of the United States Navy

MITIGATION OF SHIPBOARD INDUCED DEGRADATION ON LHD 5 COMBAT SYSTEM PERFORMANCE

Billy Douglas
and
Paul Bobrowich
Combat System Integration Division
Combat System Design Office
(SEA 06K)
Naval Sea System Command

May 1992

Approved for Public Release
Distribution Unlimited

The views expressed herein are the personal opinions of the authors and are not necessarily the official views of the Department of Defense or the Department of the Navy.

ABSTRACT

Combat system performance can be negatively influenced by the electromagnetic (EM) environment in which it operates. The shipboard EM environment is a very demanding one which has had serious impacts on combat system performance. In the past, combat system engineers would assess combat system performance prior to the actual integration of the combat system components into the ship environment. This was done to identify which combat system components would satisfy warfighting requirements. It was generally assumed that the system components would perform as required when integrated into the ship. Unfortunately, this often was not the case and as a result costly "fix-it" measures were required after the ship was built. Today, combat system engineers realize that additional combat system performance analysis needs to be conducted while designers are integrating the combat system components into the overall ship design. This paper will present a specific shipboard EM environment impact to combat system performance as well as how combat system engineers have successfully managed to mitigate the severity of this impact during the ship design process. A specific example of the utilization of recently developed performance models that allowed engineers to efficiently address this problem during the LHD 5 design will also be presented.

LIST OF FIGURES

NOTATIONS/DEFINITIONS/ ABBREVIATIONS

A	Antenna Effective Aperture (meters squared)
AAW	Anti-Air Warfare
ASM	Anti-Ship Missile
Beamwidth	The width (usually measured in degrees) of a directive antenna's main beam
EM	Electromagnetic
EMI	Electromagnetic Interference
EW	Electronic Warfare
G	Antenna Gain
Gain Reduction	Reduction in radiating antenna's main beam gain specified in decibels
P	Transmitted Power
PWS	Plane Wave Spectrum
RAM	Radar Absorbent Material
RTA	Reaction Time Available
Rmax	Maximum Radar Detection Range
Smin	Minimum Discernable Signal
Topside	Shipboard area continuously exposed to the weather, such as main deck and above

INTRODUCTION

The topside integration of numerous electronic equipments aboard Naval Warships poses many system engineering challenges. The process of locating the antennas associated with many of these systems is a unique challenge that can directly impact how well the systems will perform their functions. Microwave radar antennas have been given special attention during the ship design process because their location can directly impact how well a radar system will detect targets of interest and correspondingly how well the entire combat system will perform its mission.

Recently, combat system engineers have become well aware that the shipboard electromagnetic (EM) environment can degrade the performance of many of our electronic combat system components. Specifically, radar systems are subject to EM related performance degradation in two ways. First, degradation may be caused by the coupling of undesired EM energy into radar receivers (this is commonly referred to as electromagnetic interference or EMI). The undesired energy in many instances will emanate from other shipboard radiating systems (i.e. other radars and active EW systems). Second, shipboard structure can have significant impacts on the EM radiation characteristics of radar systems. Metallic shipboard obstacles such as pole masts and yardarms (to name just a few) will degrade a microwave radar's antenna radiation pattern which in turn will degrade the performance of the radar system itself.

This paper will specifically address the impact that shipboard obstacles have on radar system performance. In addition, the impact of radar system degradation on Anti-Air Warfare (AAW) Self Defense will be addressed to show the relationship between shipboard EM effects and overall combat system performance. An introduction describing the impact that shipboard structures have on radar antenna radiation patterns will be provided followed by a brief discussion of how this degradation will impact the AAW Self Defense Mission. Furthermore, recently developed engineering models that were utilized to mitigate this problem during the LHD 5 ship design will be presented. Finally, it will be proposed that combat system engineers are in need of additional engineering models that adequately predict combat system **performance** if they are to adequately address the problem of EMI and shipboard structure on combat system performance during the ship design process. This case will be made by exploring the concept of **Combat System Performance Margins** and in particular how they may be used (in conjunction with appropriate performance models) to save costs and improve performance during the ship design process.

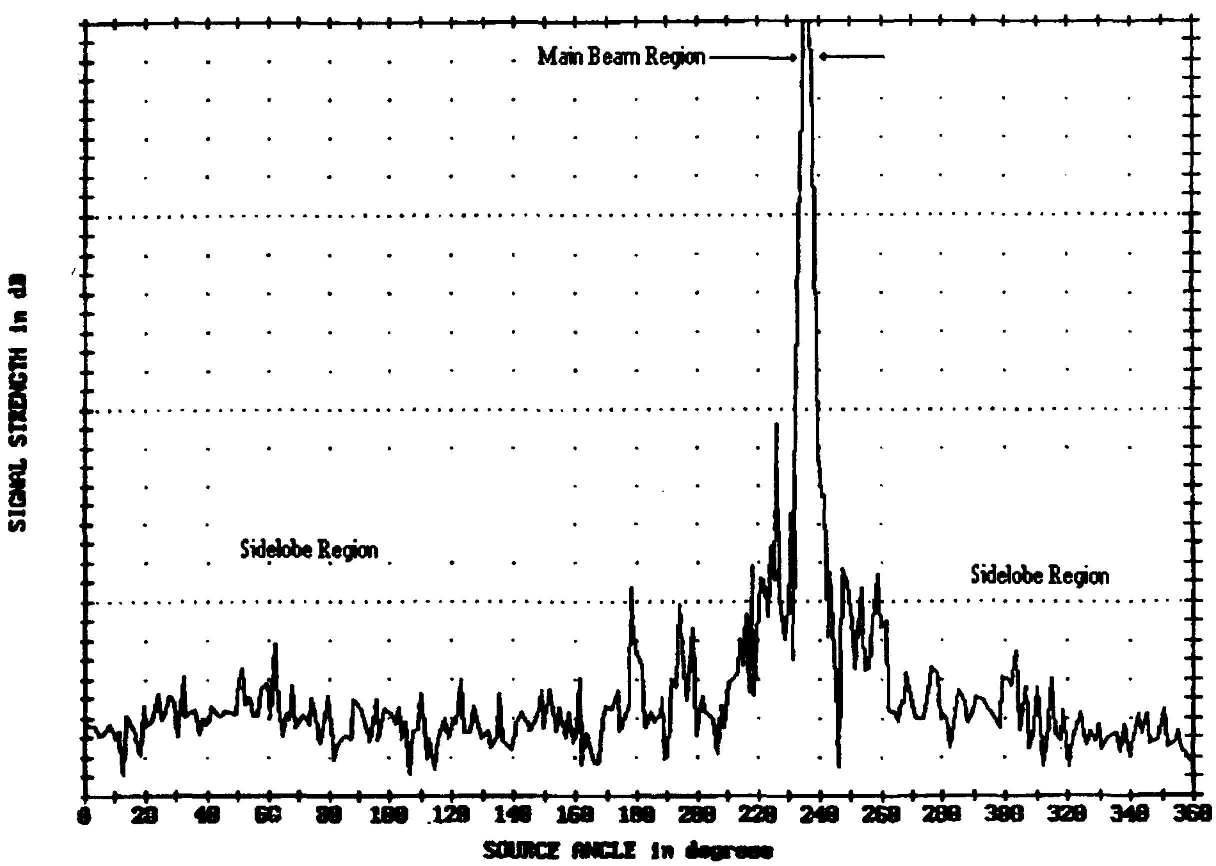


Figure 1 - Typical Microwave Radar Antenna Radiation Pattern

RADAR PERFORMANCE DEGRADATION

It is a well known fact that radar performance will be degraded when the radar "looks through" metallic shipboard obstacles. Unfortunately, most U.S. Navy air search and surface search radars have to "look through" shipboard obstacles for at least a small portion of their entire scan sectors. This is due to system engineering constraints and tradeoffs during the ship design process which generally don't allow for radars to be located on top of the mast. As a result most air and surface search radars are degraded in performance over the specific sectors where they have to "look through" obstacles.

The radar performance measures that are impacted by the presence of shipboard obstacles are:

Detection Range

Firm Track Range

and

Track Accuracy

For the purposes of this discussion, we will primarily focus upon the performance measures of **Detection** and **Firm Track Range**.

Ship structure will degrade radar performance through the degradation of the search radar antenna radiation pattern. For our purposes, the radar antenna radiation pattern may be broken up into two regions of interest:

Main Beam Gain Region

and

Sidelobe Gain Region

Antenna gain is a well understood parameter to radar system engineers and has been defined by **Skolnik** (reference [1]) as:

> "a measure of the power radiated in a particular direction by a directive antenna to the power which would have been radiated in the same direction by an omnidirectional antenna with 100 percent efficiency."

The main beam region of a radar antenna is usually described by the region where the maximum gain is achieved (this also corresponds to the region where the radar is presently "looking"). The sidelobe (or sidelobes) of the radar antenna are located outside the 3 dB beamwidth of the main beam. This is the large region where the radar is not presently "looking" but where there still is a small amount of EM energy leakage. Figure (1) represents a typical radar antenna radiation pattern where one can readily observe the main

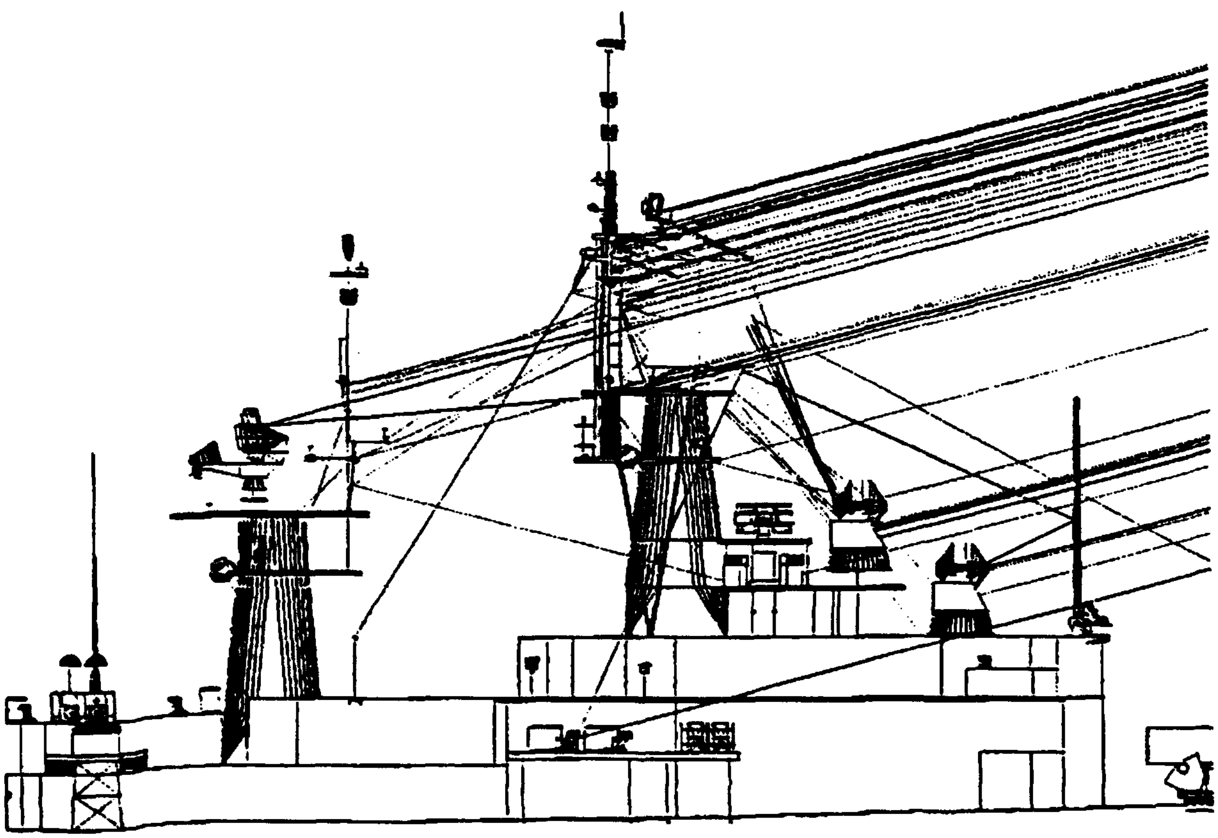


Figure 2 - Representation of EM Scattering Phenomenon

beam and sidelobe regions. This figure represents a single point in time. For an azimuthally scanning radar, the main beam region would traverse the figure from 0 degrees to 360 degrees.

Ship structure degrades radar system performance by reducing the radar antenna's main beam gain level and increasing (through the conservation of energy principle) the antenna's sidelobe levels. This is a result of the scattering of EM energy from its intended direction (where the antenna is currently directed) to other undesired directions. Figure (2) shows a pictorial representation of the scattering phenomenon. In this figure, the individual lines or rays represent the propagation of EM energy in the shipboard environment. Figure (2) was taken from reference [3] where a more complete description of the scattering phenomenon may be found. One can readily see the impact shipboard structure has on altering the direction of energy propagation. Figure (3) gives an example of the impact of structure on the antenna radiation pattern presented in figure (1). Through comparison of figure (3) with figure (1), it is evident that structure (in this case a 2 foot pole mast) can significantly raise sidelobe levels and reduce the main beam gain level. For additional examples of the impact of shipboard structure on antenna radiation patterns consult reference [2].

By reviewing the simplistic form of the radar range equation, it can be seen that the reduction in antenna main beam gain will reduce the detection range of the radar system for a given target of interest. It is readily apparent that the maximum detection range for a minimum discernable signal decreases as antenna gain decreases.

$$R_{max} = \left(\frac{PGA\sigma}{(4\pi)^2 S_{min}} \right)^{1/4}$$

Where,

A is the antenna's effective aperture, m^2

P is the transmitted power, watts

G is the antenna gain

σ is the Radar Cross Section of the target, m^2

S_{min} is the minimum received signal required to achieve detection, watts

In addition to degrading system detection range, shipboard obstacles will also degrade the radar system's firm track

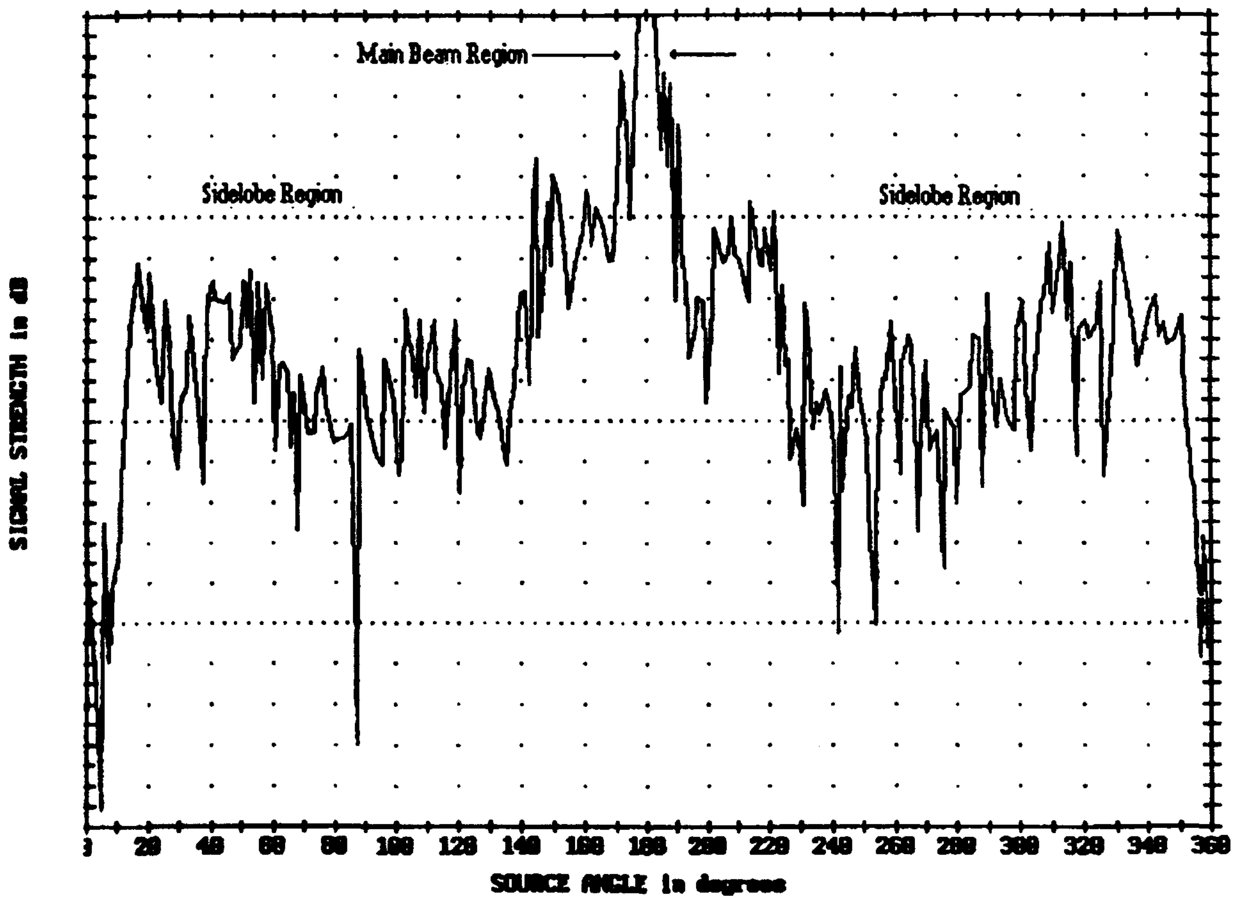


Figure 3 - Degraded Microwave Radar Antenna Radiation Pattern

range. Firm track is the range at which the radar system has received a sufficient number of detections to be reasonably certain that the returned signal is that of a target and not a false alarm caused by system noise. Normally, most radar systems will require at least two detections of a target (and quite often more than two) before it will declare a firm track. As a result, firm track range will always be less than initial detection range even without considering the impact of shipboard degradation. In the presence of shipboard EM scattering obstacles, a radar's firm track range will likely be degraded in proportion to its degraded detection range.

An increase in antenna sidelobe levels also may add to a decrease in maximum radar range performance if there exists a noise source (i.e. a jammer) or clutter in the direction where EM energy is being scattered. An increase in antenna sidelobe levels is not desirable as this increases the likelihood that unwanted energy will get into the radar receiver (unwanted in that it would be coming from a direction other than where the radar is currently looking). This (in the presence of a jammer) will raise the noise floor of the receiver and require a larger Smin to achieve maximum detection range. The Smin from the target will not get larger until the target gets closer to the radar so the result is a decrease in maximum detection range.

ANTI-AIR WARFARE (AAW) COMBAT SYSTEM PERFORMANCE DEGRADATION

Addressing radar system degradation in and of itself is not sufficient from a combat system engineering perspective (though it would be of primary concern to the radar system engineer). The combat system engineer must also assess the impact of radar performance degradation on the mission performance requirements of the ship. This is necessary to determine whether radar system degradation is of sufficient magnitude to cause deleterious effects to mission performance. Radar performance degradation which does not cause mission degradation is not a concern for the combat system engineer and resources should not be expended to mitigate that problem.

The AAW Self Defense mission has evolved into one of the most visible, important and sensitive (from a performance perspective) mission areas for most surface ships. To see how radar degradation (specifically degradation caused by shipboard structures) impacts AAW Self Defense mission performance it is necessary to introduce the AAW mission level performance measures of **reaction time** and **reaction time available**.

Combat system **reaction time** is the time required for the system to respond to a threat stimulus. In responding to a threat stimulus, the combat system performs a series of functions (see figure (4)) that are necessary to engage the threat. For the most part these functions are performed in a sequential manner and the reaction time is considered to be the time it takes for the combat system to transition from initial target detection to actual target engagement. Obviously, it is the goal of combat system engineers to reduce overall system reaction time.

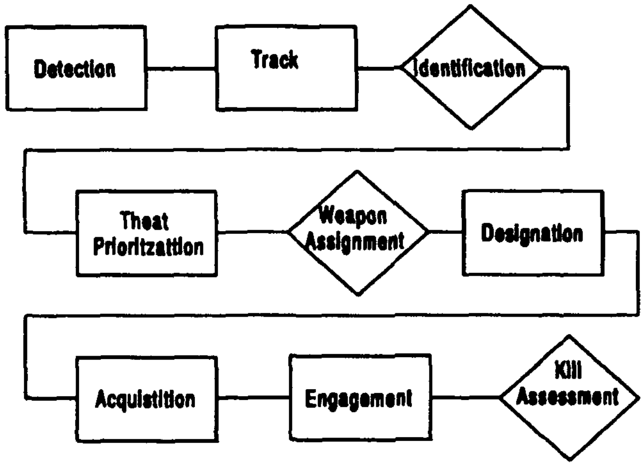


Figure (4) Combat System Self Defense Functions

Combat system **reaction time available** (RTA) defines the amount of time the ship's combat system has available to it to engage a particular threat or threats. RTA is threat dependent and will generally be greater for targets that are detected at greater distances from the ship (and move slow) than for targets that are detected at shorter distances (and move fast). Obviously, the greater the initial threat detection range, the greater will be the RTA. Finally, to successfully engage the threat at minimum weapon range, RTA must be greater than the **reaction time** of the combat system.

The previous discussion should make it apparent that detection range (as well as firm track range) is critical to the performance of the AAW Self Defense mission. If detection range is significantly reduced then it is possible that RTA will be less than the overall combat system reaction time required to respond to the threat. Now one can readily see how the shipboard EM environment (and associated structural impacts) can directly impact an overall combat system mission objective. The combat system engineer has to ensure that the shipboard environment does not decrease RTA such that it falls below the reaction time of the shipboard combat system.

APPLICATION OF ENGINEERING MODELS TO SHIP DESIGN

Plane Wave Spectrum (PWS) Model Application to LHD 5

As a result of the heightened awareness of the deleterious affects of shipboard structure on radar performance and overall combat system performance, combat system engineers in NavSea 06K decided to implement the PWS model during the LHD 5 preliminary design phase. The PWS model is an Antenna Radiation Pattern Prediction model which was developed to address the impacts of shipboard structure on an antenna's radiation pattern performance. Specifically, it predicts main beam gain reduction caused by shipboard obstacles as well as corresponding sidelobe level degradation. A detailed description of the theoretical foundation for the PWS model can be found in reference [4]. Reference [6] provides specific user, validation and additional theoretical information for the PWS model. The objective in utilizing this model was to optimize the overall radiation pattern performance for the AN/SPS-48E radar thereby optimizing its overall detection capability as installed aboard ship. The PWS model assisted in this effort by allowing engineers to efficiently predict gain reduction to the 48E's main beam as well as to predict the corresponding radiation sidelobe levels.

From the perspective of a Radar System Engineer, it would have been very desirable to locate the AN/SPS-48E radar antenna on top of the mast on LHD 5. This would have greatly reduced any structural impacts on the 48E radiation pattern. Unfortunately, due to other competing combat system requirements as well as weight and moment impacts, it was impossible to locate the antenna at that location.

The initial engineering analysis addressed the impact of ship structure on SPS-48E performance for the LHD 2 design. This effort was conducted because it was initially planned to locate the 48E antenna (on LHD 5) in the same location that it was located on LHD 2. It was apparent that the most significant impact of shipboard structure would be caused by a 4 foot pole mast located directly aft of the 48E antenna. By performing optical analysis, it became apparent that shipboard structure would impact the antenna's main beam over a sector from 120 to 240 degrees.

It was decided that a Gain Reduction analysis would be conducted over this sector at 0 degrees in elevation as this would likely correspond to the elevation of an "in-coming" anti-ship missile threat. The analysis showed that significant main beam gain reduction would occur to the 48E if it were located as it was in the LHD 2 design. The gain reduction (see figure (5)) was due in large part to the 4 foot diameter pole mast located just aft of the radar's antenna. A similar pole mast located further aft also contributed to the steep increase in gain reduction between 170 and 190 degrees. While there was little that the combat system engineer could do about the aft pole mast, the combat system

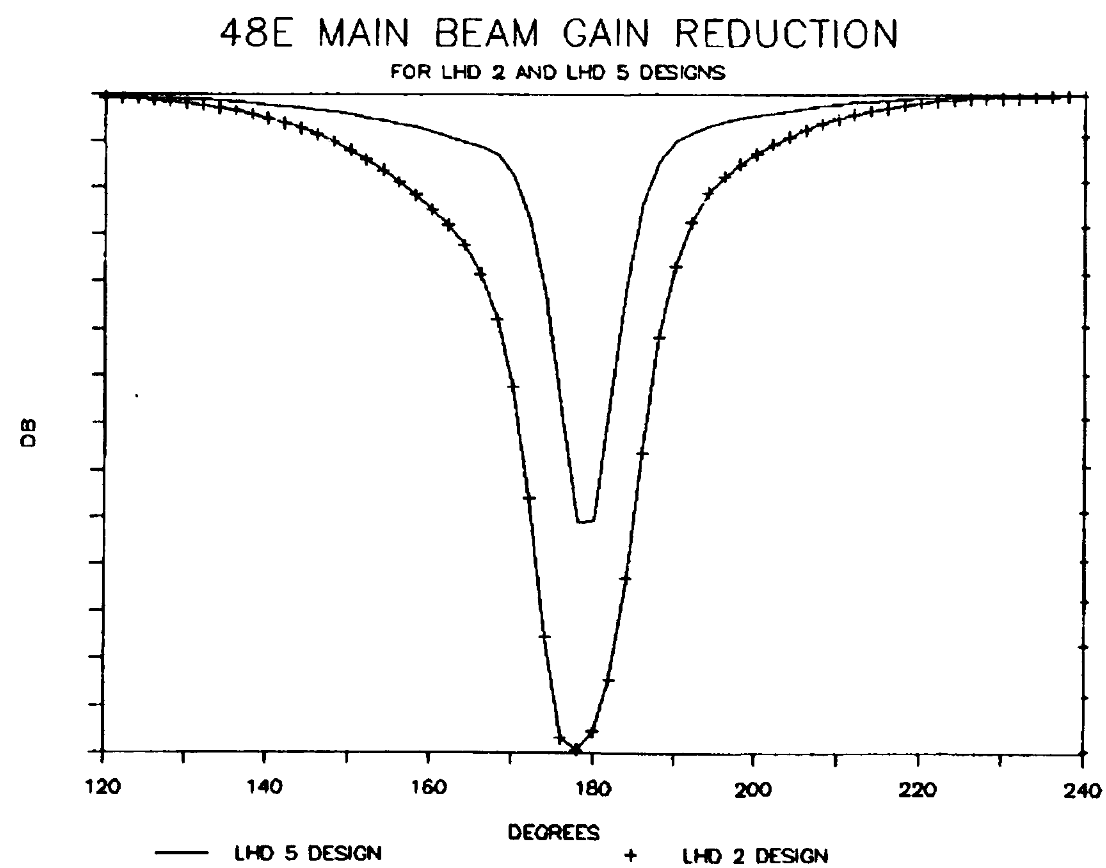


Figure 5 - Gain Reduction to AN/SPS-48E

engineer was able to influence the location of the 48E antenna within defined constraints. By being able to quantify the impact of structure on antenna radiation pattern performance, the combat system engineer was now in a position to provide a more serious case for the relocation of the 48E antenna.

The proposed alternative location for the 48E's antenna required a redesign of the forward pole mast such that it could support the weight of the antenna. This new location negated the effects of the forward pole mast by essentially locating the antenna on top of it. A new stub mast (1 foot in diameter) was now located directly aft of the 48E antenna (it was added to support the Combat DF and TACAN antennas) and its effects were relatively minor when compared to the large pole mast. Simply put, this is because the 1 foot diameter stub mast "blocks" a smaller percentage of the antenna aperture than does the 4 foot diameter pole mast. Therefore, less energy will be reflected away from the antenna's pointing direction. Figure (5) shows the new values of gain reduction to the main beam of the 48E caused by the stub mast. One can readily see the reduction in severity of the gain loss as well as in the extent (overall azimuth extent) of the gain loss. It is apparent from the analysis that there is improvement to the 48E's main beam gain by relocating the antenna.

The other function of the PWS model is to predict the overall impact of shipboard structure on an antenna's radiation pattern. The degradation to the 48E's radiation pattern did not appear to improve from the LHD 2 to the LHD 5 design even though the gain reduction was reduced significantly. Figure (6) represents the sidelobe levels for both the LHD 2 and 5 designs when the antenna is pointing directly aft (180 degrees). Note that they don't vary much in amplitude even though there is a considerable difference in the main beam gain reduction at 180 degrees. This seems to validate the concept that the shape of structure is a relatively more important consideration than the size of structure when assessing the impact of structure on an antenna's sidelobes. It was decided that instead of reshaping the stub mast, better improvement could be obtained by applying Radar Absorbent Material (RAM) to its surface area.

Radar Model Application to LHD 5

The NavSea 06K radar model was developed to analyze the impacts of the shipboard EM environment on radar system performance. The model specifically accepts EMI levels, antenna main beam gain reduction and antenna sidelobe levels as inputs. These are classified as ship impact inputs to the model and are in addition to the more conventional radar parametric inputs that are required to model any radar system's performance. NavSea 06K engineers utilize this model in assessing the impacts of the shipboard EM environment on radar detection range, firm track range and tracking accuracy. Reference [5] gives a detailed description of the radar model's capability.

Due to the classification of the analysis results for the AN/SPS-48E radar aboard LHD 5, it is not possible to present the absolute results in this paper. So that this paper may provide insight into the type of results and data produced by the Radar Model and how that data may be used by engineers, relative detection range results against a generic type anti-ship missile threat will be presented. These output results will include the impacts of main beam gain reduction calculated previously by the PWS model. It is hoped that these unclassified results will give the reader a good feel for how the Radar Model was used in conjunction with the PWS model during the LHD 5 design.

Figure (7) shows the relationship in SPS-48E detection range performance for the case where the antenna is directed aft at 180 degrees for both the LHD 2 and LHD 5. The curves represent probability of detection versus range for an Anti-Ship Missile (ASM) type target. Actual target parameters cannot be given due to their classification. The improved radar detection performance seen for the LHD 5 is a result

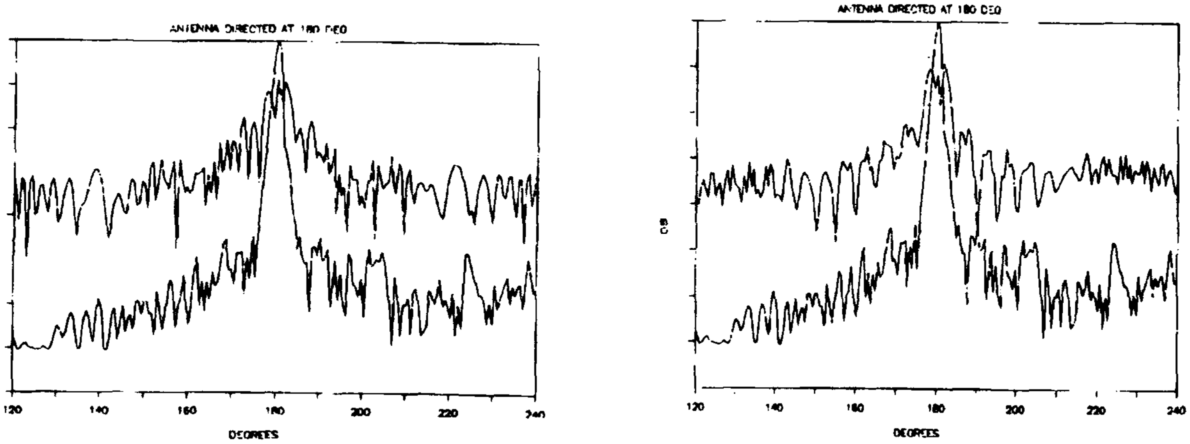


Figure 6 - AN/SPS-48E Antenna Pattern Degradation

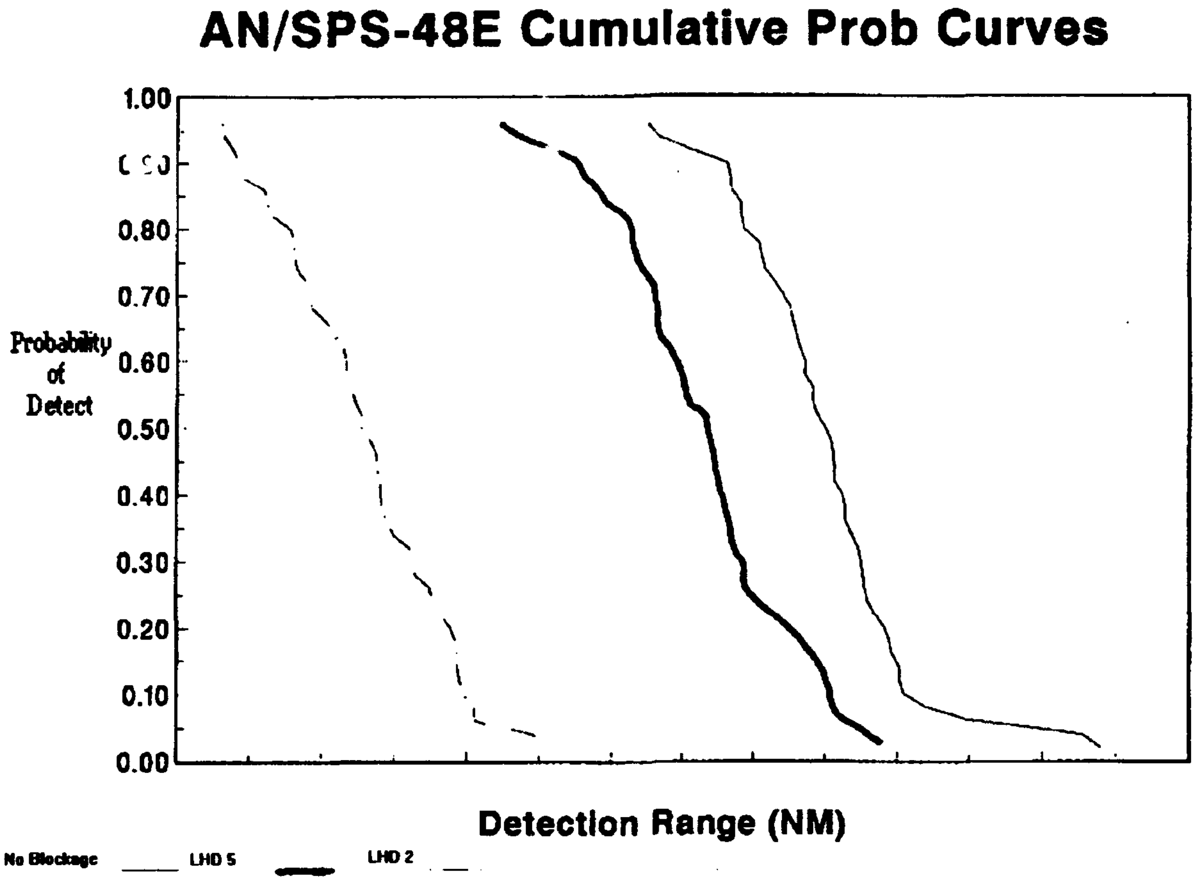


Figure 7 - Relative AN/SPS-48E Detection Ranges

of the lower main beam gain reduction value that would be expected in the LHD 5 design based upon the PWS model analysis.

AAW SELF DEFENSE COMBAT SYSTEM PERFORMANCE ASSESSMENT

The previous discussion on the PWS and Radar model applications to the LHD 5 design emphasized the AN/SPS-48E radar detection range improvement that was possible to achieve. While engineers were concerned with optimizing the radar's detection performance in the LHD 5 environment, the ultimate decision in expending resources (modifying LHD 2 pole mast design) was based on the impact of the improved detection performance on the AAW Self Defense Mission requirement. If it were shown that the LHD 5's Self Defense Mission requirement could not be met unless the 48E's detection performance were improved to that achievable by the pole mast redesign, then it would be advisable to proceed with the design modification. On the other hand, if the LHD 5's Self Defense Mission requirement could still be achieved without improvement to the 48E's detection performance, it would not be advisable to expend the resources.

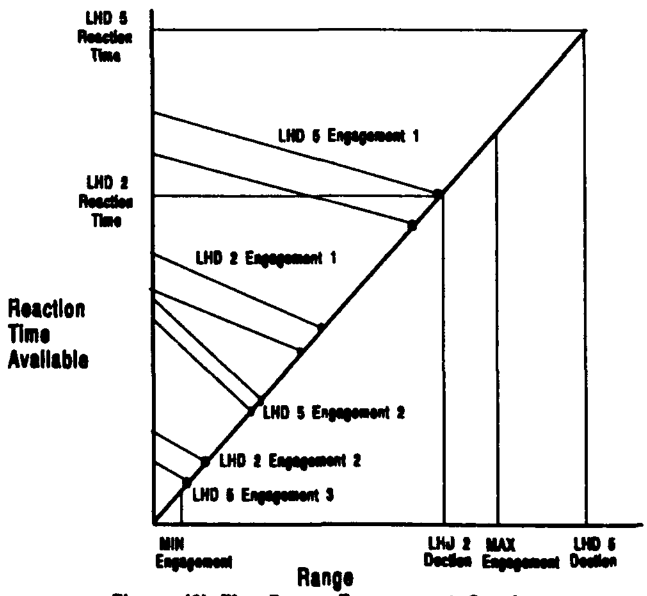


Figure (8) Fire Power Engagement Graph

Figure (8) represents a self defense engagement fire power curve that identifies the number of times the combat system can engage an "in-coming" ASM target. This figure has been considerably sanitized of classified information but is still able to convey that for a specific ASM threat velocity, there is considerably more reaction time available to the combat system when the improved AN/SPS-48E detection performance is considered. This additional reaction time available allows the self defense combat system to engage the ASM an additional time. By being able to engage the ASM three times instead of two, the overall LHD 5 self defense probability of kill requirement was now achievable. Consequently, it was deemed appropriate to proceed with the LHD 2 pole mast redesign for LHD 5.

COMBAT SYSTEM PERFORMANCE MARGINS

During the concept design stage for a Naval Warship, one of the responsibilities of the combat system engineering community is the identification of available combat system components (i.e., radars, weapons, computers, etc) that meet established combat system mission requirements. This process involves the identification of functional performance measures and the specification of associated functional performance requirements. For instance, functional performance measures such as **Detection Range, Acquisition Range, System Reaction Time,** and **Target Kill Range** are a set of performance measures that are often associated with the combat system mission area of AAW Self-Defense. Combat system engineers apply quantitative requirements to those functions by evaluating prospective combat system mission scenarios. As an example, the combat system engineer might establish a detection range of X nautical miles and an overall combat system reaction time of Y seconds in response to an envisioned worst case battle scenario. Then, the process has generally evolved to "picking" the best available combat system components to meet the performance requirements.

Traditionally, the process of "picking" the appropriate system components which best meet the performance requirements has been the last time combat system performance analysis has been performed. Generally, it has been assumed that the performance associated with a particular combat system component will remain the same when **installed** aboard ship. Unfortunately, as we have seen the shipboard environment will indeed degrade combat system component (i.e. radar) and overall combat system mission performance (i.e. AAW Self Defense) in many cases. The Concept of Performance Margins is now introduced to provide additional rationale for developing and implementing combat system performance models that appropriately model system performance measures in the **shipboard** environment.

A **performance margin** suggests that there is "room" for a particular system's performance to degrade while still being able to meet its performance objective. This implies that the system was designed to perform "better" than what was originally required. For systems that were designed to perform multiple functions, it is conceivable that they may perform less stressful functions better than required. An example relating to the AAW functions of Detect and Acquire is presented to further illustrate the concept. Typically a surveillance radar is utilized in performing the AAW Detect function. Surveillance radars generally have long range detection capabilities which support other combat system mission objectives. Fire Control radars are utilized to Acquire the target once it has been detected and generally have shorter detection ranges than surveillance radars. If the surveillance radar were degraded in its detection performance by an EM effect such as structural interference, it would not necessarily be a problem as long as the surveillance radar could still detect the target at a range greater than the fire control radar. As long as the surveillance system can detect the target before the acquisition system can acquire it, the mission objective will still be met (of course this presumes that there has been no degradation in performance to the acquisition system).

The presentation of this rather simplistic example of the performance margin concept is intended to convey that it is not always appropriate for combat system engineers to expend resources in improving a system's performance (radar system in our example) in its shipboard environment if there is an adequate performance margin available. It should be apparent to the reader that without having the means to translate shipboard environmental influences such as EM degradation effects into reliable performance degradation estimates for the affected system, it would be rather difficult (if not impossible) for the combat system engineer to determine whether or not an improvement to the combat system integration design is needed. Unfortunately, without reliable combat system performance models, the combat system engineer is left with the option of doing nothing and hoping the ramifications are not serious (i.e. an adequate performance margin is available) or trying to correct any perceived problem whether or not it is really necessary and potentially expending unnecessary resources in the process.

SUMMARY

Combat system engineers must ensure that individual combat system components are integrated into the shipboard environment so that overall combat system mission objectives will be met. This paper has presented a specific shipboard EM environmental influence relating to shipboard structural impacts on radar antenna radiation patterns. It was shown how shipboard obstacles can impact radar system performance through the scattering of the radar's EM energy in undesired directions. More importantly (from a combat system engineering perspective) it was also shown how degraded radar performance will degrade combat system mission level performance.

NavSea 06K has developed a number of engineering models that assist the combat system engineer in mitigating the impact of the shipboard environment on combat system performance. Two of these models were presented and it was shown how they were used during the LHD 5 design to improve AN/SPS-48E radar performance as well as overall AAW Self Defense performance. It is important to note that the utilization of these models during the ship design process potentially saves the Navy significant resources as combat system performance problems can be identified early on and costly post design "fixes" can be avoided.

Through the introduction of the combat system performance margin concept, it was argued that system performance degradation doesn't always prevent the shipboard combat system from meeting its mission objective. A case was made for the combat system engineering community to utilize system performance models more regularly during the latter stages of ship design (as opposed to just during the concept design stage as has been traditionally the case). By exercising system performance models that adequately address the impacts of the shipboard environment, the combat system engineer will be able to make a cost effective decision as to whether or not a modification in the design is actually needed.

References

[1]Merill I. Skolnik, Introduction to Radar Systems, McGraw-Hill 1962.

[2]Data Reduction Plots for the Shipboard Reflection Diagnostic System, METRATEK, Inc., Report No. 156 Vol. I of XVI, Oct. 25, 1990.

[3] Naval Sea Systems Command, Ray Tracing Analysis on USS ENGLAND Final Technical Report, N00024-89-C-5648, Task 69344, October 13, 1989.

[4]C. E. Ryan Jr., E. E. Weaver and B. J. Cown, Plane Wave Spectrum Scattering Analysis of Near-Field Obstacle Effects on Directive Antenna Patterns, IEEE Transactions on Antennas and Propagation, Vol. 27 No. 6, November 1979.

[5]Naval Sea Systems Command, Updated MTEM/DTE Workstation Documentation Software User's Manual, C89-794.031F/601, November 1, 1991, Revised: December 4, 1991.

[6] Naval Sea Systems Command, Ship Topside Electromagnetic Environment Effects - Final Technical Report, N00024-87-C-5208, December 1990.

THE INTEGRATED SURVIVABILITY MANAGEMENT SYSTEM: SHIPBOARD DAMAGE CONTROL GREETS THE 21ST CENTURY

Stanley Herman
Director, Ship Survivability Sub-Group
(SEA 55X)

C. T. Loeser
Assistant for Plans, Policy and Programs
Ship Survivability Subgroup
(SEA 55X)

William Davison
Senior Engineer, Damage Control Branch
(SEA 55X22)

CDR Jack Flood, USN
NAVSEA Damage Control Officer
(SEA 05X/55XD)

Naval Sea Systems Command

May 1992

Approved for Public Release
Distribution Unlimited

The views expressed herein are the personal opinions of the authors and are not necessarily the official views of the Department of Defense nor the Department of the Navy.

Abstract

This paper addresses the NAVSEA approach to automate and significantly accelerate the shipboard damage control decision process.

The volume and complexity of the data required to support Damage Control decision making has defied attempts at manual management. Today's Damage control personnel utilize large diagrams displaying ship arrangements and systems, and plot the presence of casualties and damage control progress with grease pencils. Communications are accomplished by phone or messenger. Recent experiences in the Falklands Islands and in the Persian Gulf have shown that improved weapons accuracy and speed of delivery have increased the need to respond more quickly and correctly to the effects of damage caused by those weapons.

The Integrated Survivability Management System (ISMS) will significantly enhance the Damage Control process by merging traditional survivability efforts with improved communications and computer support. ISMS will provide improved coordination of information among command locations, including the bridge, Combat Information Center (CIC), Damage Control on-scene leaders and personnel stationed in Damage Control Central (DCC) and the Damage Control repair stations. ISMS will be survivable and reliable. It will provide sensing, communication and display of information to support analysis, planning, decision making and control. This will accelerate the damage control process, minimizing the spread of damage and maximizing the remaining mission capability of the ship.

Prototype portions of ISMS are now at sea on selected ships. NAVSEA is working closely with the Fleet to ensure that the man-machine interface is optimized. Since ISMS is intended to be an evolutionary system, the plans call for near, mid and far term Fleet implementation.

LIST OF TABLES

LIST OF FIGURES

NOTATIONS/DEFINITIONS/ ABBREVIATION

ADM	Advanced Development Model
AFFF	Aqueous Film Forming Foam
CBR	Chemical, Biological, Radiological
CBR-D	Chemical, Biological, Radiological Defense
C3	Command, Control, Communications
CCOL	Compartment Check-off List
CIC	Combat Information Center
CNO	Chief of Naval Operations
CO	Commanding Officer
COMOPTEVFOR	Commander Operational Test and Evaluation Force
CPS	Collective Protection System
CSMC	Combat Systems Maintenance Central
CSOOW	Combat Systems Officer of the Watch
DC	Damage Control
DCA	Damage Control Assistant
DCAMS	Damage Control Asset Management System
DCC	Damage Control Central
DCMS	Damage Control Management System
DCTT	Damage Control Training Team
DOP	Development Options Paper
DTRC	David Taylor Research Center
EDM	Engineering Development Model
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
ETR	Estimated Time to Control and Reconfigure
FSED	Full Scale Engineering Development
GFE	Government Furnished Equipment
GFI	Government Furnished Information
GUI	Graphical User Interface
HM&E	Hull, Mechanical and Electrical
HULLCOM	Hull Communications
HVAC	Heating, Ventilation and Air Conditioning
ILSP	Integrated Logistic Support Plan
ISMS	Integrated Survivability Management System
LAN	Local Area Network
NSWC	Naval Surface Warfare Center
NSWCCDDTMB	Naval Surface Warfare Center, Carderoc Division, David Taylor Model Basin
NSWCCDNAVSSES	Naval Surface Warfare Center, Carderock Division, Naval Ship Systems Engineering Station, Philadelphia
OPNAVINST	Chief of Naval Operations Instruction
PCO	Prospective Commanding Officer
PKP	Purple-K-Powder (Potassium bicarbonate)
PQS	Personnel Qualification System
PXO	Prospective Executive Officer
RM&A	Reliability, Maintainability and Availability
TAO	Tactical Action Officer
TOR	Tentative Operating Requirement
TSS	Total Ship Survivability
UPS	Uninteruptable Power Supply
WIFCOM	Wire-free Communications

BACKGROUND

In recent years ship survivability has been challenged in incidents involving USS STARK, USS SAMUEL B. ROBERTS, USS PRINCETON and USS TRIPOLI. All of these ships survived initial weapon damage, and after repairs were returned to service. This performance is a reflection of passive survivability features built into NAVY ships and highly effective damage control measures that were taken. Today, the world is increasingly becoming divided into relatively small, often belligerent countries, that have access to increasingly more powerful weapons including indiscriminately used Chemical, Biological and Radiological (CBR) weapons. Our Navy can expect continued exposure to traditional or even more powerful threats. Ship survivability, including damage control, must continue to improve at a higher rate to enable ships to cope with faster, more accurate and more powerful weapons.

Damage control includes all procedures, ship design features and on-board equipment necessary to minimize and contain the effects of casualties; restore vital Hull, Mechanical and Electrical services; improve stability; exclude and decontaminate CBR agents and protect personnel.

Damage control management consists of information acquisition, processing and display necessary to provide command, control and communications for damage control decision making by the battle organization under casualty conditions. Damage control management is traditionally performed manually; that is, communications, investigations and decision making are totally made by the human element.

The major deficiency in the way we conduct damage control today is the time involved from the identification of damage to the corrective action taken in controlling damage and restoring mission capability. A secondary, but not insignificant, deficiency is our inability to know the actual condition (ie., *load status and resultant inherent stability) of the ship* prior to, and immediately following, actual damage.

In addition, modern ship combat, propulsion, electrical and auxiliary machinery systems have become have become increasingly complex, supported by computer programs, flexible as to configuration and alignment and have become more time sensitive with marrower tolerances for precision control. The increasing sophistication of these systems has not yet been accounted for in damage control (DC) information and decision aided management systems.

The objective of damage control is to achieve the highest potential of maintaining operational readiness and to preserve the warfighting capability of the ship, both in hostile and peacetime environments.

To better understand what ISMS can do for the damage control organization to enhance ship survivability, it can be looked at relative to a major conflagration. A major conflagragation is damage of a magnitude that cannot be readily handled by the conventional damage control organization; therefore, all hands participation is required to save the ship. The ship will have lost many damage control systems as well as experienced mass personnel casualties. Using the lessons learned from the USS STARK we clearly see the need for development of an integrated survivability management system.

USS STARK's major conflagration has been well documented *in the Formal Investigation*, NAVSEA Lessons Learned Package and the first hand accounts from crew members of USS STARK, USS LASALLE and USS CONYNGHAM. The need for ISMS can be first seen when the crew begins damage assessment of the impact of the missile hits (the trajectory and explosion damage radius), the building of the conflagration and total damage inflicted from fires and flooding as a result of *primary and secondary* damage. A centralized assessment was almost non-existent during the first several hours of this incident, which almost instantaneously, was a major conflagration.

Sustained damage included severe structural stress, fires with temperatures above 2000 degrees F, flooding of large *centerline compartments, ship's stability approaching the* danger angle, almost one-third of the crew killed or wounded, uncontrolled vertical fire spread, loss of vital systems including firemain and command communications systems. The physical location of the fires and structural damage actually divided the ship into isolated segments with communication networks between segments almost nonexistent. Although the ship was saved by heroic damage control actions by the crew and rescue and assistance units a centralized control of these actions took hours to develop.

The Integrated Survivability Management System (ISMS) is being developed to significantly improve our performance in these areas. Since damage control not only addresses efforts taken after damage occurs, but also includes efforts made to ensure that the ship is in its most survivable state prior to damage, ISMS will be designed to support both parts of the damage control effort, particularly the management of damage control.

In order to understand and fully appreciate what ISMS will actually do for the Navy, we must first understand how the current damage control process works. We will break it down as follows:

(a) the damage control organization

(b) the damage control process

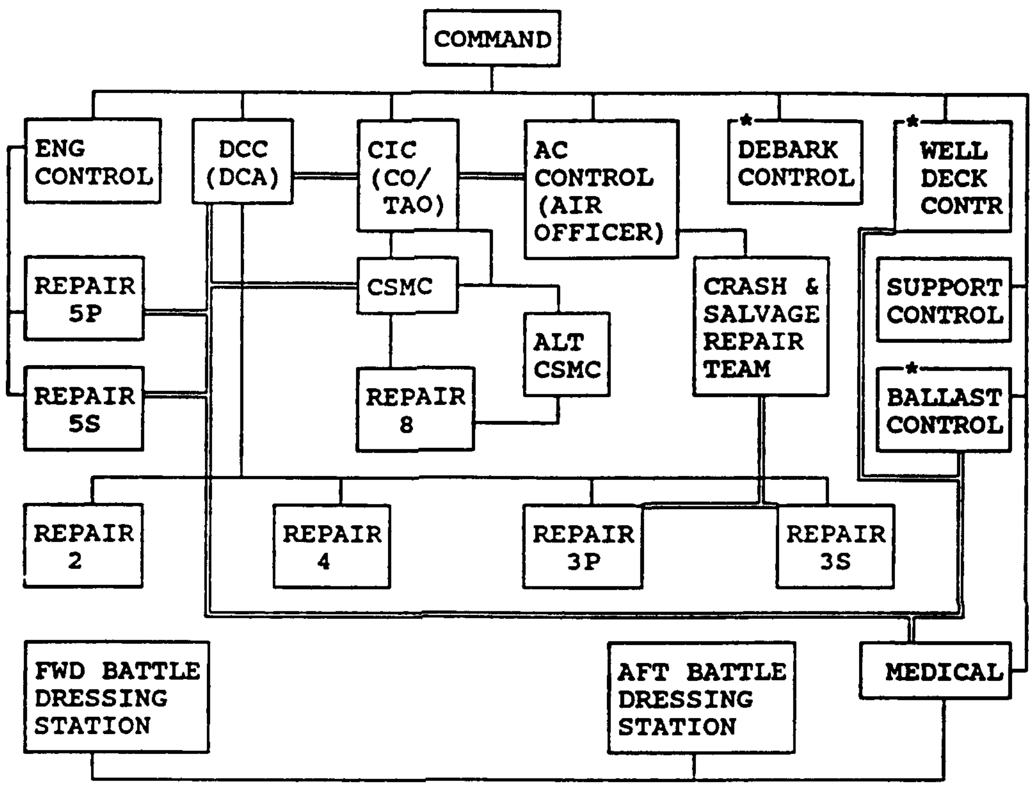
(c) the damage control management.

Then we will introduce ISMS, describe how it will function, and discuss the near and far term program.

DAMAGE CONTROL ORGANIZATION

Shipboard damage control is a process carried out by a significant portion of the shipboard organization. The Condition I (General Quarters) battle organization which supports damage control is shown in Figure 1. [1] These decision making stations are organized and integrated to accomplish specific functional tasks. Many of the functional tasks are accomplished by more than one station, and are all supported by, primarily, a manual management system. A management system must support information transfer between these stations and desisions made at these stations.

The Commanding Officer (CO) has the responsibility of maintaining his command in a state of maximum effectiveness for war service, and after battle or action, to immediately repair damage and exert every effort to prepare his command for further service. The CO has the functional task to continuously remain appraised of the damage control situation, and to redirect damage control evolutions in response to the tactical situation. Accurate communication



Legend:

- command
- coordination
- * Condition IA only

Figure 1 – Battle Organization

to him, in a timely manner, directly affects his decision process. In Condition I the CO is typically located in either the Combat Information Center (CIC) or the bridge as dictated by the current defensive posture and internal ship conditions.

Damage Control Central (DCC) is the nerve center for damage control activity and the point of coordination with command and the other damage control stations shown in Table 1. This is the Damage Control Assistant's (DCA's) battle station. When the ship is at Condition I the DCA reports directly to the CO. He informs the CO of conditions and potential conflicts that affect the ship's ability to conduct its mission. The DCA must also accurately assess the impact of damage to the ship and informs the CO of his recommendations for mitigation. Coordination of all hands is paramount to effectively contain and control weapon induced and/or accidental damage. The key to doing this is proper coordination by the DCA of all resources available to him. Table 2 shows the types of reports made by the DCA to the CO.

Repair parties, the functional elements of the damage contol organization, are located at repair stations and report directly to the DCA. A repair party is a group of approximately 15-30 trained personnel located at one of several stations

Receive and evaluate information from repair parties.

Inform command of conditions affecting the material condition of the ship, including buoyancy, list, trim, stability and watertight integrity.

Initiate orders to repair parties, as necessary, to direct control of damage. Support the coordination/direction of damage control actions among repair parties and other damage control stations to restore the ship's weapons systems, mobility and other mission capabilities to enable the ship to continue to fight.

Obtain command approval for those damage control measures that require the CO's approval.

Control watertight integrity, flooding, counterflooding and dewatering.

Maintain two way communications with repair parties, engineering control, CIC, CSMC, bridge, medical and support control (and debarkation control, aircraft control, well deck control, conflagration stations, and ballast control when provided).

Maintain an up-to-date casualty board showing the damage sustained and corrective action in progress.

Maintain a stability board showing liquid loading, the location of flooding boundaries, effect of list and trim caused by flooded compartments and corrective actions taken with regard to stability.

Maintain a list of preplanned routes for ready and deep shelter, combat system casualty control, battle dressing and battle logistics.

Maintain a graphic display showing action taken to correct disrupted or damaged systems.

Maintain a closure log showing the state of closure of the ship.

Maintain a CBR contamination prediction plot.

TABLE 1
FUNCTIONS OF DAMAGE CONTROL CENTRAL

Type and location of fires and when extinguished.

Presence of dense smoke and when cleared.

Location, rate, depth and cause of flooding, and when controlled.

Type and location of weakened structure, and when shoring is completed.

Any electrical power loss to equipment and rigging and energizing of casualty power.

Any ruptured piping which may affect vital systems or cause flooding.

Any personnel casualty that will affect the performance of a battle station.

Any damage that affects watertight integrity.

Location and intensity of radiation hot spots and when decontaminated.

Table 2
REPORTS FROM DAMAGE CONTROL CENTRAL TO THE COMMANDING OFFICER

Evaluate and correctly report the extent of damage in the area to DCC. Maintain a graphic display board showing damage, and action taken to correct disrupted or damaged systems. Make repairs to electrical and sound powered telephone circuits. Administer first aid and transport injured personnel to battle dressing stations without seriously reducing the damage control capability of the repair party. Detect, identify, measure dose and dose-rate intensities from radiological involvement, survey and decontaminate personnel and areas. Detect and identify chemical agents and decontaminate areas and personnel affected as a result of biological or chemical attack. Control and extinguish all types of fires. Assist the DCA in maintaining stability and buoyancy by: Repairing damage to structures, closures or fittings that are designed to maintain watertight integrity, by shoring, plugging, welding, caulking the bulkheads and decks, resetting valves and blanking or plugging lines through watertight subdivisions of the ship. Sounding, draining, pumping counterflooding or shifting liquids in tanks, voids or other compartments. Maintain two way communications between the repair party leader and repair party personnel involved with damage control. Maintain two way communications with DCC and the other repair parties. Maintain and make emergency repairs to vital systems within their area of responsibility, such as HVAC, compressed air, internal communications and electrical systems. Provide casualty power to vital electrical equipment.
TABLE 3 SPECIFIC REPAIR PARTY FUNCTIONS

which contain damage control communications and management support equipment. A repair party officer commands the repair station. Damage control tools and equipment are stowed in the station and in the surrounding area. A typical destroyer will have three or four damage control repair stations, a carrier will typically have more than ten. The destroyer's repair stations are located forward, aft and amidships. Each of the repair stations has responsibility for containing damage, extinguishing fires and restoring vital Hull, Mechanical and Electrical (HM&E) services in its area

REPAIR PARTY 3 Provide backup to crash and salvage repair team. Maintain two way communications with aircraft control (if provided). REPAIR PARTY 5 Maintain, make repairs or isolate damage to main propulsion machinery. Assist in the operation and repair of the steering controls systems. Relieve ship's propulsion personnel in the event of casualties. Maintain an engineering casualty control status board showing the condition of readiness of main propulsion and principal auxiliary machinery.
TABLE 4 ADDITIONAL FUNCTIONS OF SPECIAL REPAIR PARTIES

of the ship. On a three repair station ship the amidships repair station protects the propulsion spaces while the remainder of the ship is geographically divided equally between the forward and after repair stations. Larger ships have additional repair stations arranged such that each repair station has responsibility for a reasonable portion of the ship. When a casualty is detected, the repair party will take action immediately, and the repair party officer will inform the DCA of the actions taken and of the ship's condition. The DCA will provide command and control necessary to integrate the individual repair party's actions with the total ship operation. Repair parties may share resources such as tools and people to provide them where needed to effectively combat the casualty. Repair party functions are listed in tables 3 and 4.

Engineering control is under the leadership of the Engineer

Evaluate and correctly report the extent of damage in area of responsibility to DCC and command.
Maintain two way communications with DCC, command and Repair Party 5.
Coordinate and direct the damage control action of Repair Party 5.
Maintain a graphic display board showing damage and action taken to correct disrupted or damaged main propulsion or auxiliary equipment or services.
Control and extinguish all types of fire in designated main propulsion and auxiliary compartments.
Control and restore main propulsion and auxiliary equipment and services casualties.

TABLE 5
ENGINEERING CENTRAL DAMAGE CONTROL FUNCTIONS

Direct and coordinate the damage control actions of CSMC, including combat systems reconfiguration and repairs.
Maintain an up-to-date casualty board showing the damage sustained and corrective action in progress.
Maintain two way communications with CSMC, DCC and aircraft control (if provided).
Report all combat system casualties to the command, DCC and CSMC.

TABLE 6
COMBAT INFORMATION CENTER DAMAGE CONTROL FUNCTIONS

Officer who manages the operation, maintenance and repair of main propulsion and auxiliary equipment and services during battle conditions. Damage control related functions are contained in Table 5.

Combat Information Center (CIC) is under the leadership of the CO, Combat Systems Officer of the Watch (CSOOW) or the Tactical Action Officer (TAO), who manages maintenance prior to, and operation after, damage to the combat systems equipment. The CSOOW directs and coordinates damage control actions of combat systems maintenance central (CSMC) including combat systems reconfiguration and repairs. Damage control related functions are contained in table 6.

CSMC directs and coordinates the reconfiguration of combat systems and combat system support services and of the combat system equipment.

Aircraft Control, if provided, manages damage control evolutions on the flight deck. These include communications with the local repair party, CIC, debarkation control and command. Aircraft Control supervises the damage control actions of the crash and salvage repair team, extinguishes helicopter and aircraft fires, and makes expeditious pilot rescue and aircraft salvage operations on the flight deck. It also repairs damaged flight decks and associated equipment.

Debarkation Control, if provided, manages damage control evolutions that concern the embarked vehicles and cargo. This involves the emergency handling of damaged vehicles or the removal of damaged cargo.

Well Deck or Hangar Deck Control/Conflagration station, if provided, manages damage control evolutions that concern the embarked aircraft on the hangar deck or assault craft, vehicles and cargo in the well or hangar deck.

Ballast Control manages damage control evolutions that concern the ballasting/deballasting of the ship.

Support Control is manned by personnel from the Supply Department, and is prepared to provide emergency issuance of parts and messing during battle conditions.

Medical is manned by medical department personnel, and is equipped to handle personnel casualties. Immobile injured personnel are usually transported to the battle dressing stations by repair party stretcher bearers.

DAMAGE CONTROL PROCESS

The general damage control process includes containment, extinguishment, isolation, reconfiguration and restoration. Containing damage includes closing watertight fittings to stop progressive flooding, using and cooling fire resistant barriers to slow the spread of fire and smoke, and using the Collective Protection System (CPS) and countermeasures wash down system to exclude Chemical, Biological and Radiological (CBR) agents. Damage control personnel extinguish fires using water, HALON, AFFF, CO_2, PKP or other methods. In order to isolate damaged portions of a system, the damage control personnel must secure the valves or trip the circuit breakers on either side of the damage. Where systems are configured for survivability, a path around the damage may be established by opening valves or closing circuit breakers. Restoration includes dewatering, desmoking, pipe patching, running jumper cables for electrical power or for communications, constructing shoring, decontaminating CBR agents, overhauling the fire.

DAMAGE CONTROL MANAGEMENT

Damage control management consists of surveillance, communications, display, assessment, planning, decision making, command, control, training and administration. Damage control management is currently supported by personnel, systems and equipment as described below. The repair party officer and the DCA each conduct damage control management at their own level. The repair party officer manages activity within his area of responsibility and the DCA manages damage control activity throughout the ship.

Surveillance: Investigators, assigned to each repair station, patrol the repair station area of responsibility and look for signs of damage. An investigator must be able to recognize and identify casualty situations, determine the location, and report to the repair station. The investigator must report a broad spectrum of casualties and casualty effects including hull damage, pipe damage, flooding, high bulkhead or deck temperature, smoke, fire, electrical arcing, tank contamination and tank soundings. The investigation is lengthy and time consumming; there is considerable area to cover and the investigator must be extremely cautious. Inital reports to the repair station are provided by WIFCOM or installed phone systems, followed by a written message carried to the repair station by a messenger.

Sensors are also provided for surveillance. Ultraviolet, high temperature, temperature rate of rise and/or smoke sensors, depending upon the ship class, may be provided for fires. Special high temperature sensors are provided in magazines. Flooding sensors, actually high bilge level alarms, are provided for machinery spaces located below the waterline. These sensors cause alarms to sound in DCC.

Pressure gages are provided to monitor the pressure of each segment of the firemain in condition Zebra.

Displays: Information converging on the repair station over the WIFCOM, sound powered phones, ship's telephone, amplified voice system or by messenger is plotted on a large display, the damage control diagram, using a standard symbology. The symbology has been developed over the years to enable quick plotting and recognition of any type of casualty and the status of actions being conducted to alleviate the casualty. Figure 2 shows examples of the symbology. The damage control diagrams display the ship's arrangements isometrically, deck by deck. The diagrams also show the ship's systems. Showing all systems on one diagram would be extremely confusing; therefore, each system is shown on a separate diagram superimposed on the isometric view of the arrangements. Table 7 lists the systems shown, and Figure 3 shows a representative system diagram. Using these diagrams the repair party leader can assimilate information from several independent observations and quickly see interrelationships between casualties, determine the combat system equipment that is affected by HM&E system casualties and determine access routes to the casualty location. Much of this information is plotted by the senior damage control condition I watchstander on damage control diagrams in DCC.

Flooding Effect and Liquid Loading
Subdivision
Main and Secondary Drainage and Clean Ballasting Systems
Plumbing, Gravity and Miscellaneous Drains
Sounding Tube Deck Plates and Sewage Disposal System
Tank Stripping System
Firemain, Sprinkler, Foam and Washdown Systems
Fuel Filling, Transfer and Overflow System
JP-5 Filling, Transfer, Service Stripping and Overflow System
Ventilation Systems, Supply and Recirculating
Ventilation Systems, Exhaust
Chilled Water System
Compressed Air System
Casualty Power Supply and Casualty Communications Systems
Vital Damage Control Electrical Equipment and Power Supply Chart
Communication Directory

TABLE 7
SYSTEMS SHOWN ON DC DIAGRAMS

In addition to the diagrams, the DCA has displays of alarm indications and a display of firemain pump and valve status. The fire alarm indications are typically displayed on a dedicated console panel showing an inboard profile of the ship and the spaces where the alarms have been installed.

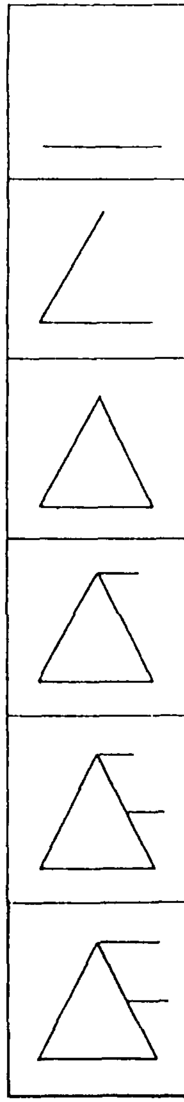
STANDARD SYMBOLS TO BE USED FOR DAMAGE CONTROL REPORTS

TYPE OF CASUALTY	LETTER SYMBOL AND METHOD OF REPORTING						
Fire	A, B, or C	Reported	Under Control	Out	Reflash Watch Set	O_2 Test Safe	Overhauled
Smoke	S	Reported	Being Cleared	Cleared		O_2 Test O_2 Safe	
Flooding	F	Gals. or Feet	Being Pumped	Dewatered	Compt. Secured		
Hole	(Size)	Reported	Patching or Plugging in Progress	Plugged or Patched	Compt. Secured		
Shoring	K	At Scene	50% Completed	Completed	Watch Set		
Electrical	E	Power Lost	Circuit Deenergized	Power Restored			
Communications	(Circuit)	Lost	Being Repaired	Restored			
Ruptured or Ruptured Line	R (System Abb.)	Reported	Isolated	By Passed	Repaired		
Personnel Casualty	P	Reported	Medic at Scene	Restored or Evacuated			
Fire Boundaries	FB	Ordered		Set	Secured		
Flooding Boundaries	FLB	Ordered		Set	Secured		
Nuclear Contam.	100R/H N	Reported	Isolated	Decon Underway	Decon Completed		
Biolog. Contam.	(Agent) B	Reported	Isolated	Decon Underway	Decon Completed		
Chem. Contam.	(Agent) C	Reported	Isolated	Decon Underway	Decon Completed		

LIST OF ABBREVIATIONS FOR REPORTING DAMAGE

AH - Armored Hatch	
AP - Air Ports	HJ - Hot and Jammed
ATC - Air Test Cap	HPAV - High Pressure Air Valve
ATD - Air Tight Door	HRSOV - Handling Room Sprinkler Cut Out Valve
C/C - Compartment Cleared	LPAV - Low Pressure Air Valve
C/D - Compartment Demolished	MPAV - Medium Pressure Air Valve
C/F - Compartment Flooded	MSCOV - Magazine Sprinkler Cut Out Valve
C/P - Casualty Power	NAD - No Apparent Damage
C/U - Cool and Unjammed	NAED - No Apparent Electrical Damage
CWSW - Contaminated with Salt Water	NTD - Non Tight Door
DDV - Deck Drain Valve	ODF - Over Board Discharge Fitting
E/C - Emergency Communications	PS - Passing Scuttle
FFC - Fixed Fog Connection	PV - Plumbing Vent
FLWV - Flushing Water Valve	QAD - Quick Acting Door
F/M - Fire Main	QALS - Quick Acting Escape Scuttle
FMCOV - Fire Main Cut Out Valve	QAH - Quick Acting Hatch
F/M/R - Fire Main Riser	RCV - Remote Control Valve
FMRV - Fire Main Riser Valve	SCV - Stop Check Valve
FMV - Fire Main Valve	STC - Sounding Tube Cap
FP - Fire Plug	STWV - Sounding Tube with Valve
FTD - Fume Tight Door	SWE - Salt Water to Eductor
FWV - Fresh Water Valve	VC - Vent Cover
FZ - Fire Zone	WTD - Water Tight Door
GSV - Gagged Scupper Valve	WTH - Water Tight Hatch

SYMBOLOGY MESSAGE BLANK



FROM		TO
________	OSL	________
________	INV	________
________	R-2	________
________	R-3	________
________	R-5	________
________	BRIDGE	________
________	CCS	________
________	DCC	________

COMPARTMENT: ________

FRAME(S): ________

REMARKS:

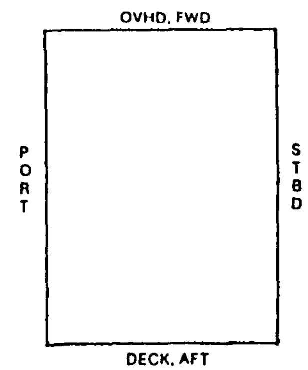


Figure 2 – Damage Control Symbology

TYPICAL DAMAGE CONTROL DIAGRAM

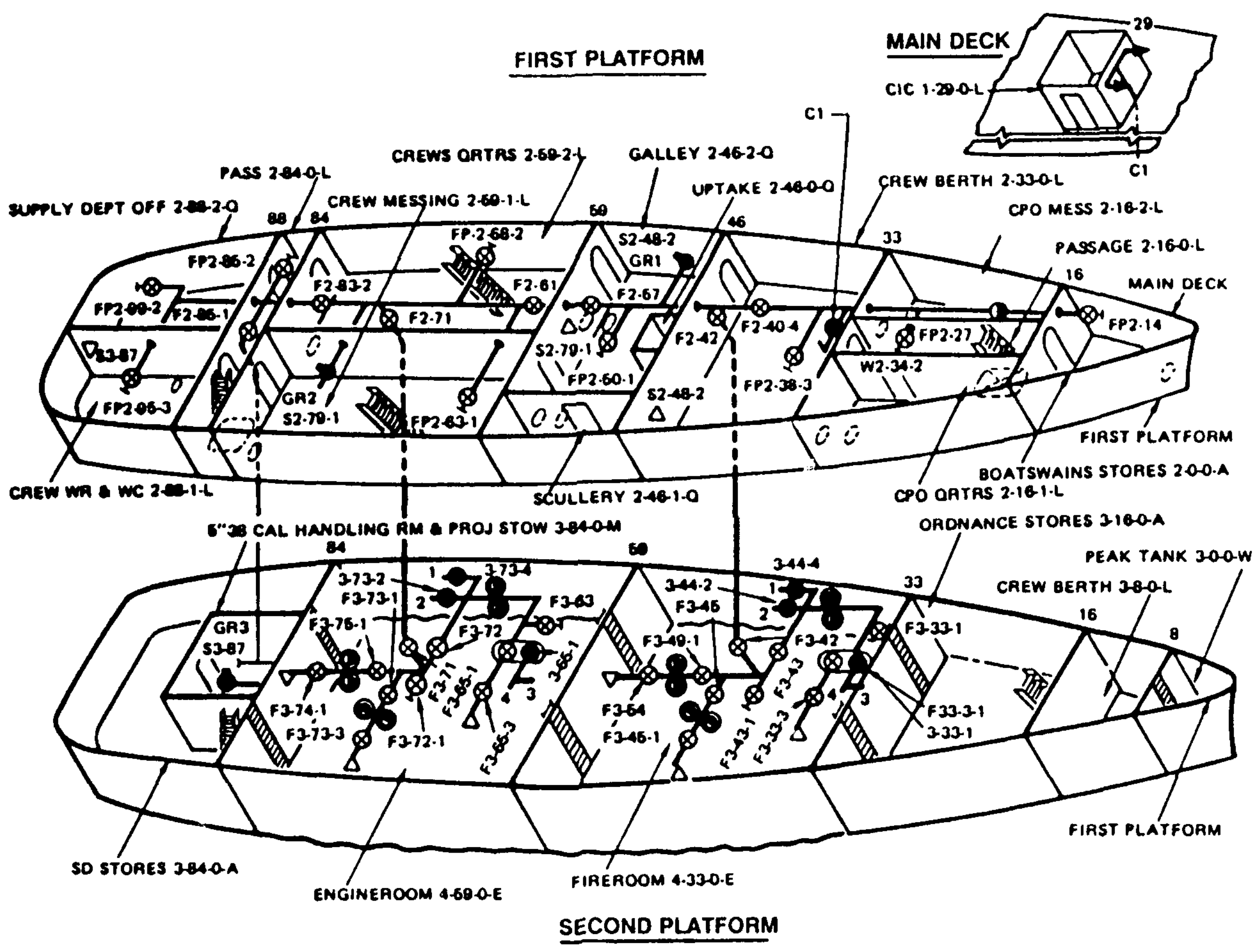


Figure 3 – Damage Control System Diagram

The flooding alarms and magazine high temperature alarms are generally displayed on independent bulkhead mounted panels. The firemain pump and valve indications are displayed on a system mimic.

Damage control diagrams are provided on the bridge for display of the status of damage control actions.

Assessment: The DCA and repair party officer each use their displays to assess the individual casualty, determine what is happening, and gage the extent of the casualty. Assessment involves analyzing the casualty in relation to the overall situation, to vital ship systems and current tactical situation. It includes the prioritization of casualties. Rarely is the entire situation clear at first, information from many sources may be needed to assess the cause of the casualty and its extent. Assessment also includes computations to maintain stability, buoyancy and development of a radiological evaluation.

Plans of action: The DCA and the repair party officer each develop alternative plans of action. In most cases the actions are straightforward; however, where several casualties are occurring at once, alternative plans and available resources are considered, coordination with other ship departments and among damage control stations are accomplished, and impacts on ship's mission capability are determined.

Decision, Command and Control: The DCA and the repair party officer each decide on a course of action, and issue orders to his organization. The repair party officer will execute his plan and report his actions to the DCA along with the estimated time to control and reconfigure (ETR). The DCA will modify or negate repair party officer's orders. The DCA redirects the actions of the repair party officer where mission or overall ship's readiness status can more effectively be improved by an alternative course of action. The DCA accomplishes coordination with other departments. In some cases the DCA can take action directly using remote controls that may be provided for the firemain and the ventilation systems. Typically, ships are provided with control of the fire pumps and valves necessary to energize required pumps, and control vital valves and ventilation dampers and fans. In addition, controls of the water washdown system, flight deck sprinkler system, overhead sprinkler systems, machinery space HALON and AFFF systems and magazine sprinkler systems are provided at various locations at DCC or within a repair station area of responsibility.

The DCA receives feedback and progress reports via messenger or phone, and plots these on his damage control diagram. A glance at the diagram now identifies the casualties, pinpoints their location and shows the status.

The DCA will keep the CO and other DC stations appraised of progress in addressing casualties, new situations, and the impact of damage or damage control activity on ship mission capabilities.

Asset management: The location and availability of all damage control assets including personnel, tools, equipment, and consumables for all damage control activities must be optimized for the particular ship, and must be known by all who may use them.

Training: The damage control organization requires training in order to achieve and maintain proficiency. Training includes periodic on-board training drills using realistic shipboard simulation of damage. However, the shipboard exercises are not enough to achieve and maintain damage control effectiveness. Damage Control Training Teams (DCTT) report aboard periodically to train and evaluate the crew. In addition, training at fleet schools is required for most of the repair party members. The DCA must ensure that all personnel who may conduct damage control operations are properly trained, and that personnel substitutes, due to absence or casualty, also have received appropriate training.

Administrative support for damage control includes maintaining the training records and maintaining the compartment check-off lists (CCOL). The CCOL, posted in each compartment, is a summary of all damage control fixtures and equipment in the space including access closures, damage control valves, communication devices, ventilation fans and ventilation closures. It is used by the investigators and repair party personnel to locate damage control fittings and equipment. It is also used by the Damage Control Petty Officer responsible for the space to properly maintain all damage control equipment and fittings and by inspectors checking the damage control material condition of the ship. Inevitably changes are made to damage control fittings and equipment during overhauls requiring the updating of the list. These updates are made by the ship's force.

PERFORMANCE MEASURES

The effectiveness of the current shipboard damage control management system is measured in terms of the restored mission readiness of the ship, and the time it takes to achieve that state of readiness, following damage or accident. This effectiveness is acheived when the functions of the damage control organization outlined above can be carried out quickly and accurately.

At any time the net loss of capability within any mission area is the combination of the capability lost caused by initial weapons effects and the additional capability lost from secondary weapons effects less the recovery of capability due to damage control actions.

After the initial weapon effects, the damage control organization must contain the spread of resulting damage. The primary variables are the time required to react, and the effectiveness of the response. The total reaction time depends on:

-determining type and location of weapon effect

-communicating this information to decision stations
-displaying the information
-integrating the information with the ongoing activity
-developing plans of action
-initiating commands
-executing the commands.

Subsequent changes in the situation require the same response sequence. The effectiveness depends on the accuracy and speed by which the above is managed. Lessons learned from past casualties highlight deficiencies in the existing damage control management system. Apparent deficiencies include:

Surveillance: There are inadequate quantities and types of sensors currently used in the fleet. Sensors must be of better quality, and better distributed so that fire, smoke and flooding can be more readily detected and measured. Human investigators, used to locate casualties, and human messengers (if radios are not available) used to transmit the data by written word, slow the process significantly. Also, human investigators may not be able to determine the location of the casualty; ie., smoke or flame may prevent determining the location of the fire source, or identifying that flooding is occurring. In addition, conflicting information may be obtained from other investigators. Finally, the limited number of investigators may not be able to expeditiously uncover several simultaneous casualties.

Communications: Most casualty reporting and command communications are transmitted by voice. This has three drawbacks: (1) Errors can be made in voice communication, (2) Voice communication takes time, and (3) Voice communications to more than one level in the organization must be accomplished serially.

Displays: The current displays are effective in that they utilize concise symbology which shows the type and location of the casualty and the progress taken in addressing the casualty. However, the displays may be inaccurate due to communications difficulties between stations. The displays may contain excessive detailed information; for example, the DCA who only needs to see the top level situation must now see the combined detail plots of all the repair stations. This detail can be confusing if not properly managed. Information is not correlated; it is displayed on a variety of panels in differing forms. Displays are usually "out of date" due to the time required for transmission of the latest information from the various stations to DCC. All displays are not updated simultaneously, and this compounds the problem.

Assessment: Rapid assessment of the information provided is essential to providing effective corrective actions. Inaccurate assessments can lead to exacerbating the damage. For example, it is nearly impossible to manually perform accurate and timely stability and buoyancy calculations under battle conditions. This can lead to improper, or no, actions to correct a worsening stability situation.

Plans of action: Coordination among departments and among damage control stations may be slowed and confused because situation plots may be at variance with each other. Valuable time may be required to sort out the actual situation.

Decision, Command and Control: Commands may be confused as they are transmitted along the verbal communications paths. Not only is excess time expended, but an improper response could result. Coordination may be slowed, and conflicts in situation plotting may result.

Feedback: Feedback may be slowed by the verbal communications path, and it may not be provided to all stations simultaneously.

Asset management: The current damage control management system does not include asset management. This information is maintained "mentally" by damage control personnel. Since each damage control repair station contains more than 400 items, accurate accounting under battle conditions is nearly impossible.

A vital damage control component, assumed to be at the station, may not be there.

Training: Ships do not routinely conduct total ship damage control training. Such training drills are difficult to plan because of the complex interrelationship of ship systems in a damaged condition. Physically damaging the ship or the vital equipment is not practical. The training that is given, while extensive, does not normally represent the actual situation that could exist, and is limited in scope.

Administrative support: Training records are not available to the DCA during battle conditions to assist in reassignment of personnel who become casualties. Most ships do not have support for maintenance of CCOLS.

BRIDGING THE GAP

In the 1980s, it was apparent that the current damage control process, a process that is similar to that used during WWII, had to be upgraded to meet the challenges of today and tomorrow. Several concepts were investigated, all using some type of automated data processing, and several breadboard units were built and tested. The goal was to significantly speed up the decision making process by providing rapid and accurate information to the decision makers. This action alone would revolutionize the damage control process as we know it. Thus, in concert with OPNAV 03, the Integrated Survivability Management System (ISMS) program was initiated.

A Tentative Operational Requirement (TOR) [2] for the system was promulgated in September of 1988 which initiated a program to utilize computers to eliminate the deficiencies listed above. The TOR has governed system development through the Development Options Paper (DOP) [3] completed in 1990. The TOR provides the following systems description of ISMS:

.....is envisioned to consist of redundant computer(s), interfaces, databases/software, sensors, auxiliary systems switching, portable display units for repair parties, consoles for Damage Control Central (DCC) and secondary DCC, displays for the Commanding Officer, Mission Area Control and HM&E, and back-up power supply. This system will continuously gather and monitor key data. It will then process, analyze and prioritize the data to formulate and recommend courses of action, including the ability to automatically and rapidly switch from primary to alternate sources of auxiliary support for combat systems. Appropriate officers will then direct DC personnel action while abreast of casualty status. The system shall be designed to gracefully degrade to a configuration which requires minimal distributed system support...... [2]

Three systems were proposed in response to the TOR:

(a) Providing of courses of action for damage control situations and independent computer support for firefighting, stability and other damage control functions.

(b) All of the features of the first option and the ability to accomplish actuation manually through remote control.

(c) A total ship system using artificial intelligence, and including the automatic remote activation of all damage control equipment, providing display and control at the Bridge and CIC in addition to DCC. [3]

The version of ISMS currently under development falls between the first and second options. This new option emphasizes the acquisition and display of key data in a manner that will readily support the decision maker. The focus of this option is the display. While this system employs existing sensors, the need for additional sensors is recognized, and improved sensors continue to be a focus of development. The current level of existing equipment and systems control is not affected by ISMS.

ISMS development supports the survivability policy addressed in OPNAVINST 9070.1, Survivability Policy for Surface Ships of the U. S. Navy, and the current approach to ship design. OPNAVINST 9070.1 states that "The Chief of Naval Operations (CNO's) goal is to maintain ship operational readiness and preserve warfighting capability in both peacetime and hostile environments." [4]

We now turn to a discussion of ISMS, as currently envisioned. Although alterations to the program may ensue, it is expected that the basics will remain as shown herein.

High temperature fire sensor
Temperature rate of rise
Ultraviolet fire sensor
Particulate smoke
Magazine high temperature
Bilge level
Water level
Tank level
Firemain pressure
Firemain valve position
Pump status
Ventilation fan status
Chemical Agent Point Detector
Sprinkler activation
HALON activation
AFFF activation
CPS zone pressure
Electronic equipment cooling system pressure and temperature
Gyro failure alarm
Dry air system pressure
Compressed air pressures
List
Trim
Drafts
Toxic gas (including Freon, H_2S, CO)
Explosive gas (including Hydrocarbons)

TABLE 9
SENSORS

THE INTEGRATED SURVIVABILITY MANAGEMENT SYSTEM (ISMS)

HARDWARE ARCHITECTURE

The hardware architecture is designed to support damage control personnel at each station by providing information and allowing control through the console's graphical user interface (GUI). The consoles are in turn supported by a common data communication bus. The bus serves as a link not only between the consoles but to the sensors and controlled devices. The redundant consoles and data busses are essential survivability features.

The hardware architecture is shown in Figure 4. It is based on the organizational structure and the functions of the damage control battle stations discussed earlier. This architecture is compatible with any future shipwide Integrated Platform Management System or Integrated Machinery Control System. The architecture is "transparent" to the data bus technology and topology, because the console/workstation will employ standard Navy interfaces to the data bus. The architecture requires a redundant, survivable bus architecture for data connectivity together with an uninterrupted power supply (UPS) for the DCC console and each workstation.

The data communications network supports the sensor to network communications flow, the inter-console data flow and the control signal data flow. The voice communications networks support hardwired voice communications and the wirefree voice communications. Manual data entry is also supported. Survivable communications will be provided by the HULLCOM system, which transmits voice and data via hull structure. In addition, a portable data entry unit will be provided for on scene communications. See Figure 5.

Ventilation zone stop
Firemain pump
Firemain valve
Magazine flooding
Machinery space AFFF bilge flooding
Machine space HALON flooding
Hangar deck AFFF sprinkling
Well deck sprinkling
Flight deck sprinkling
Hangar deck division bulkhead closing
Countermeasures water washdown system

TABLE 10
CONTROLS

The sensors providing surveilance input to the system via the data communications network are listed in Table 9. Sensory data is converted to alarms as required. Valve position for firemain will be expanded to other systems after proof is done. Through the use of color video displays multiple alarm conditions taken from single sensors can be indicated. An an example: as compartment temperature rises to 90 degrees F, the compartment condition could be shown in yellow and at 105 degrees and above it would be shown in red. The consoles supported are those shown in Figure 4. The capabilities that are currently supported listed in Table 10 will be included with the ISMS console.

Hardware Requirements:

Environmental: The hardware must operate reliably in the normal shipboard environment. This includes temperature extremes, vibration, EMI, EMP, and humidity. Initially we intend to use commercial grade hardware. Following the research and development demonstration we will require militarized, marine suitable hardware.

Survivability: Since ISMS is a system which supports ship survivability, it must itself be survivable. Each installation must be designed to incorporate the survivability principles of separation, redundancy and multiple sources. As described above each station will have an UPS, and the communications network will be survivable. The hardware will survive shock and exposure to water. Redundancy is inherent to the system, since each console or work station will have the capability to control the network. The consoles will be located in stations which are physically separated. The hardware and software will be developed so that upon loss of one or more consoles, the remaining consoles will continue to operate, and network control will shift as necessary. Loss of some sensors will not result in degradation of the operation of undamaged sensors.

SOFTWARE ARCHITECTURE

The software architecture is shown in Figure 6. This consists of software to support network control, display, analysis and a database. All software resides at each console or workstation.

Network Control: Network control is usually at the DCC console. Here, the network control software controls the network data flow. Data enters the system as sensor signals or as manual input from the DCC console or any workstation. All data is checked for conflicts before being accepted by the system. Conflicts are resolved or identified before data is accepted by the system. Network control software shifts control of the ISMS operations to a surviving station if the controlling console or workstation is destroyed.

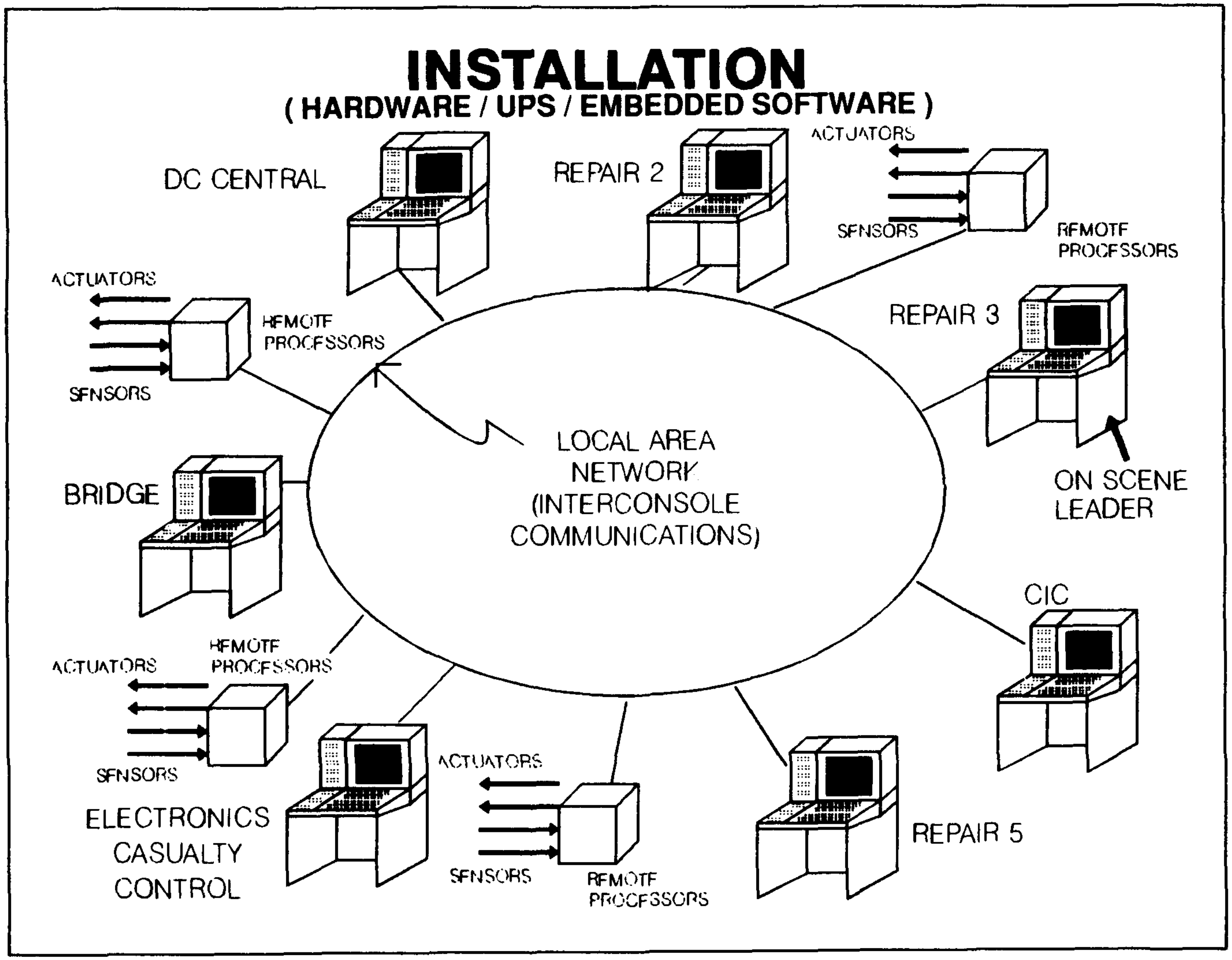


Figure 4 – ISMS Hardware Architecture

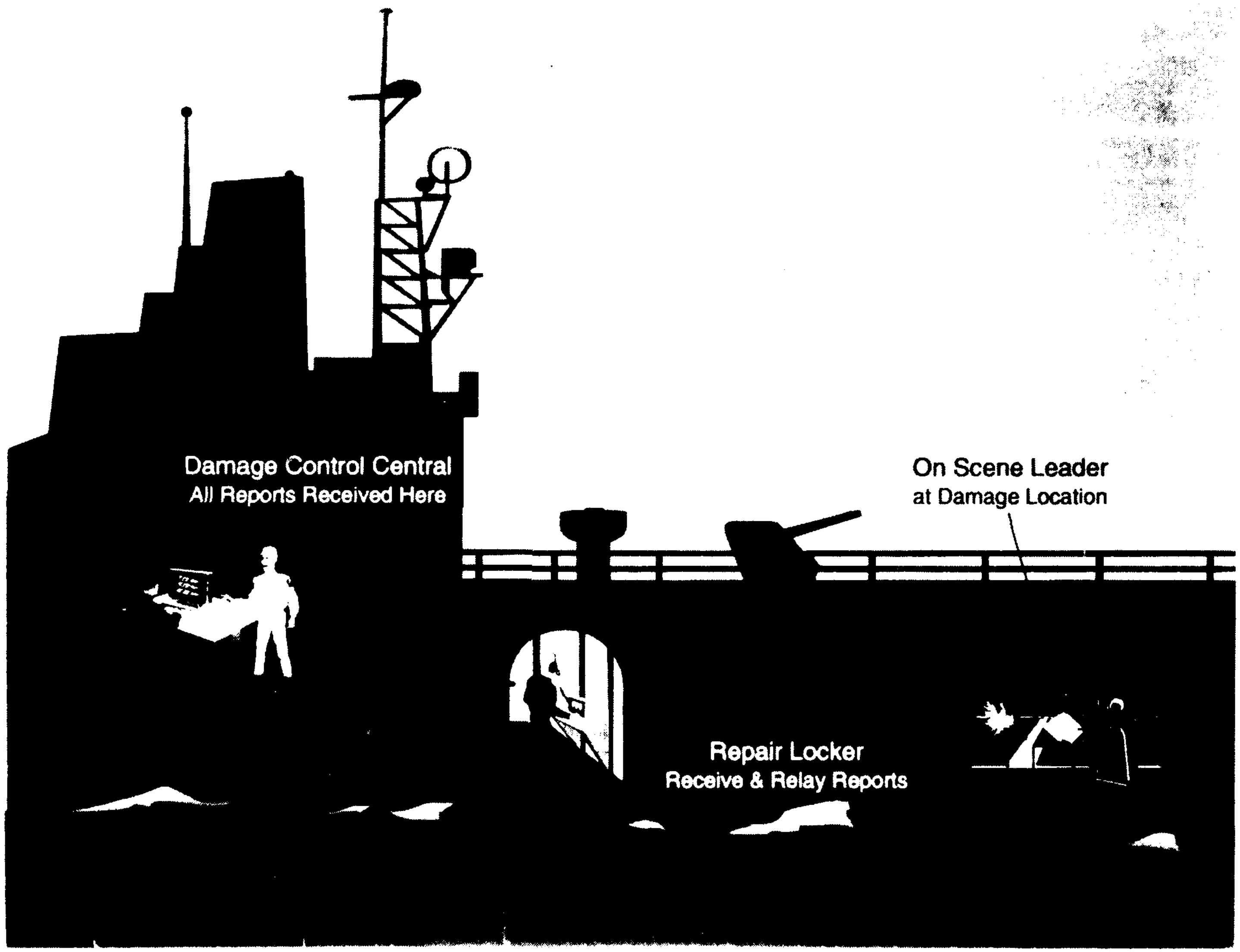


Figure 5 – On Scene/Investigator Electronic Data Communications

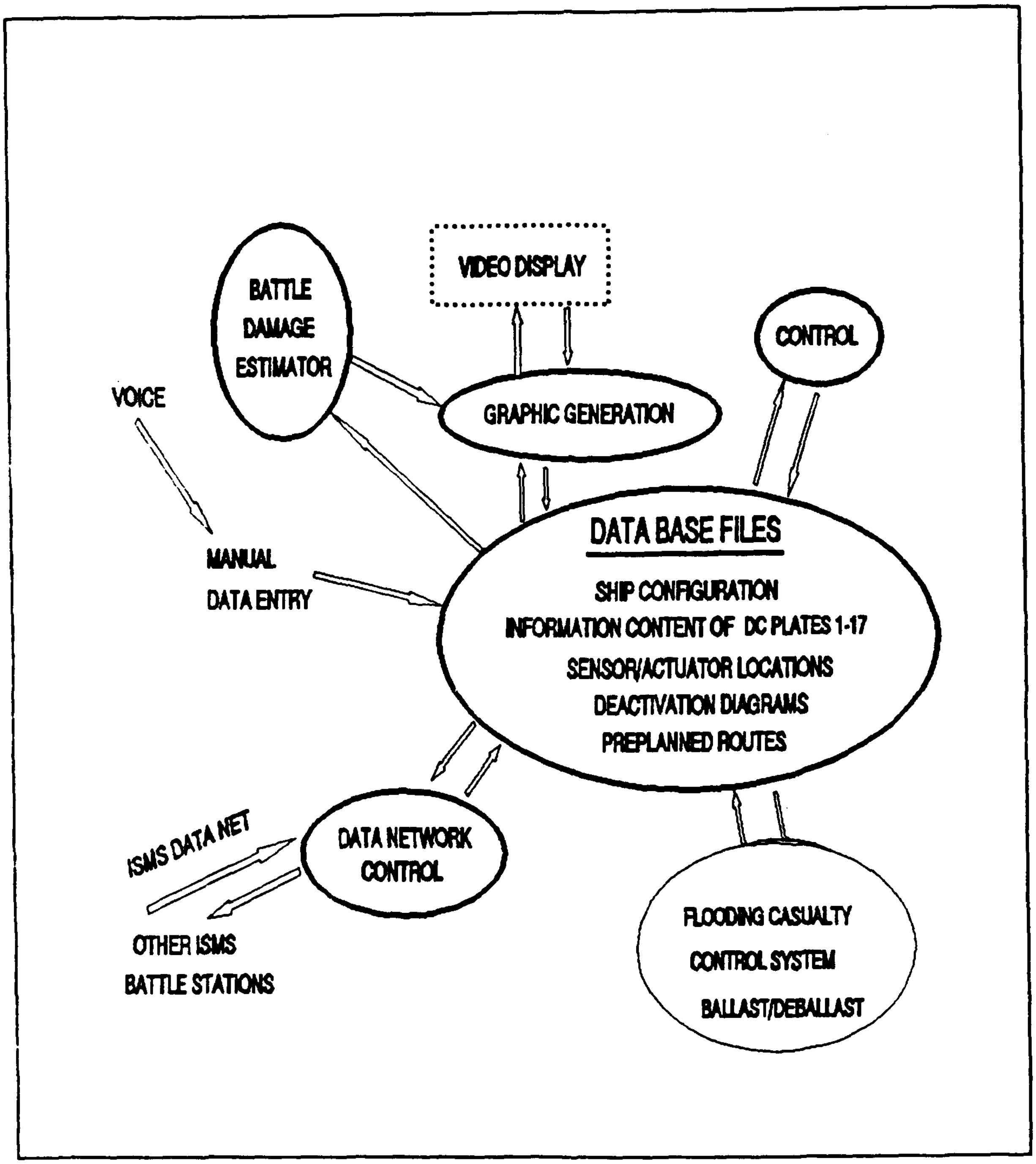


Figure 6 – ISMS Software Architecture

Control actions are those actions required to start and stop equipment, activate firefighting systems, and change the position of valves to reconfigure systems. Control actions can be taken from any workstation on the network.

The network control sends control signals to physical devices. Designated actuators and equipment will be remotely controlled by the DCC console or by the workstation in control of the network. The operator will be able to either make the command directly by a manual input, or call up the appropriate screen for a reference code, and then make the appropriate manual entry. When activation is confirmed by sensor, the change of state will then be entered into the database, and become part of the next data base update sent to all workstations.

The damage plot having the information content of all the DC diagrams, damage reported and entered into the system, and summary plots.
Damage to specific systems.
Routes for access/egress.
Administrative documents.
Firefighting.
Flooding and stability.
Ballasting/deballasting control (as required)
Vital system/DC systems management.
Readiness assessment.
Embedded training.

TABLE 11
DISPLAYS

Display: The display software resides at each console and workstation. The displays created are based on the information currently in the console or workstation database.

The ISMS displays will be capable of rapidly providing information to the operators in an easy to understand format. These displays will be accessible with a minimum number of operator actions. The system will provide direct access to any functional area. Rapid transfer to the more detailed displays of the damage will be available. The DCC console and each workstation will have the capability of displaying the information in Table 11 and described below:

Summary Damage Display: This is the damage plot. It includes the information equivalent of the damage control diagrams with all damage plotted. Its basis is the ship's arrangements, as shown in Figure 7. In addition, information about location of combat system, HM&E and DC equipment, location of repair parts, medical facilities and supplies, the fresh water system and the location of alarms will be included on the display. The damage plot will display the closure log exceptions to the material condition of the ship. When damage data is entered, the display will present the damage data using appropriate symbology. See Figure 8. The summary displays will notify the operator when an alarm occurs, and will provide quick access to details such as type, location and acknowledgement status. The summary displays will show the general location of the damage, fire and flooding boundaries and status of actions taken to combat the damage.

Summary plots are also required for the combat, propulsion, and electrical systems as well as for any other combat mission systems. A summary plot showing the status of all the ship's weapon systems is required for command decision making.

Specific Systems Damage Display: ISMS will be capable of displaying damage to the specific systems that are presented on the damage control diagrams. See Figure 9. The damage to specific systems will be presented on the display screen which contains the system schematic, and on the screen which shows the location of the components and equipment involved. Rapid access to both screens either directly or from the summary graphics will be available. In order to evaluate these complex systems, ISMS will be capable of "zooming in" to expand segments of each display. To eliminate clutter; layering of details, such as frame/deck and component numbers, will be available with the "zoom" feature.

Control: Displays will allow system control. See Figure 10. The display will indicate the status of the equipment and whether control is available. Manipulating the display will enable control of the equipment.

Routing information: ISMS will be able to provide routing information for rapid movement of personnel and material for routine and damage conditions. Preplanned routes will be stored in the database, with user-demand display capability. Route modification will also be available, prior to and/or post damage.

Administrative documents: These administrative documents will be supported: closure log, readiness assessment, emergency routing, supply support parts location, DC and HM&E status log, liquid loading management, tagout log, cargo stowage plan, cargo priority list, personnel training qualifications, manning status.

Firefighting: ISMS will be capable of providing firefighting decision aids. Firefighting displays will show the location, type, fire and smoke boundaries and status of fires on the

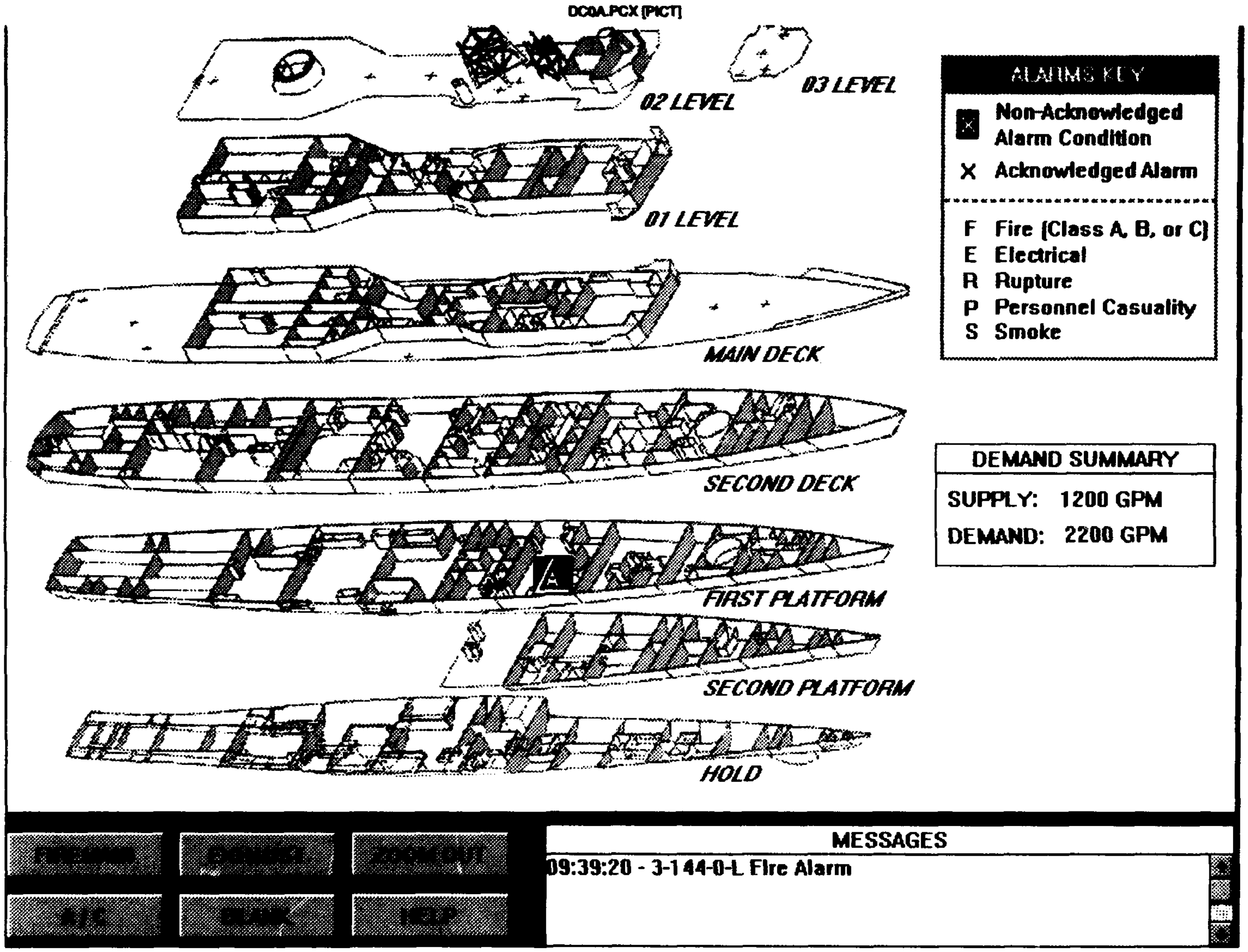


Figure 7 – Ship Arrangements Display

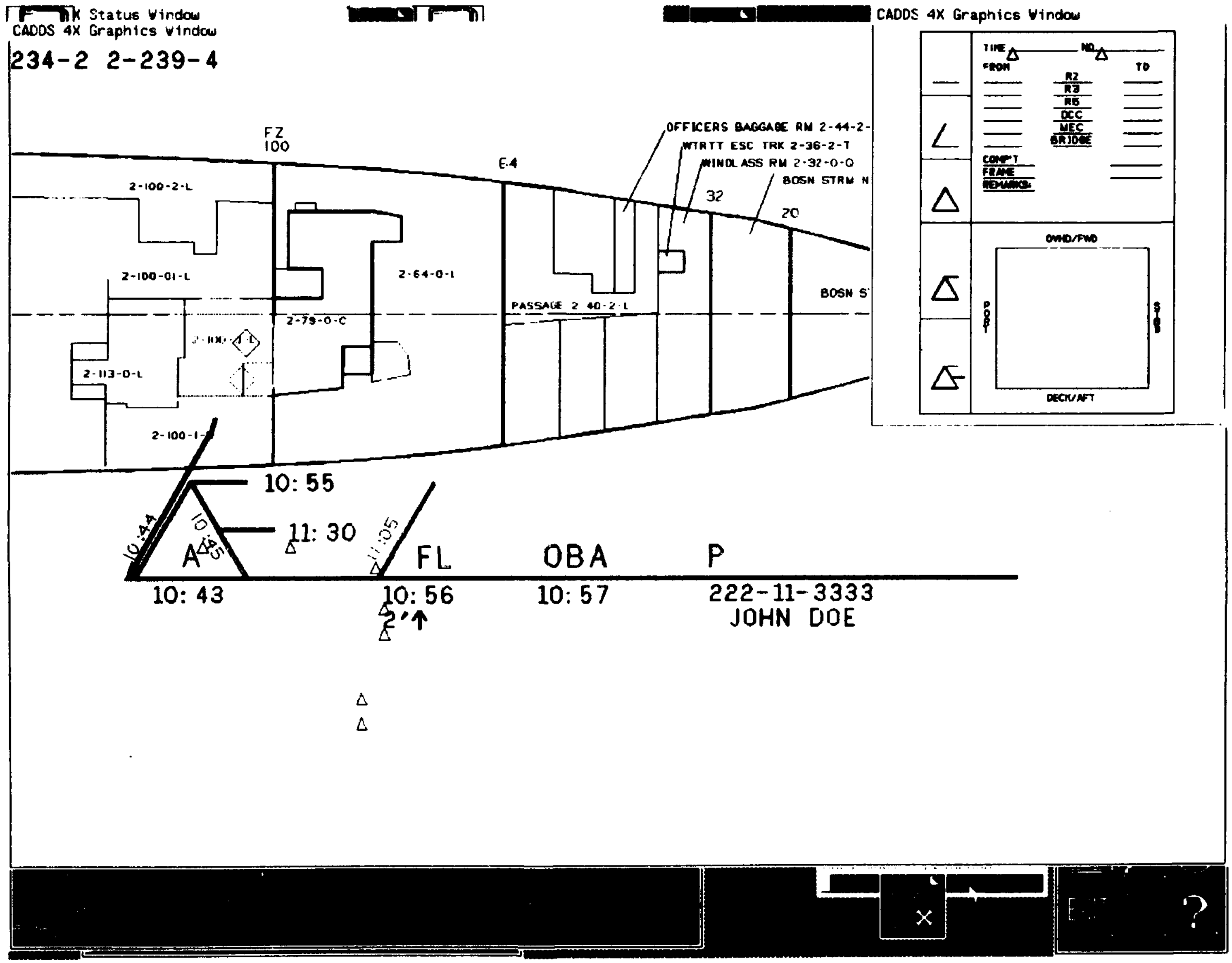


Figure 8 – Damage Plot Display

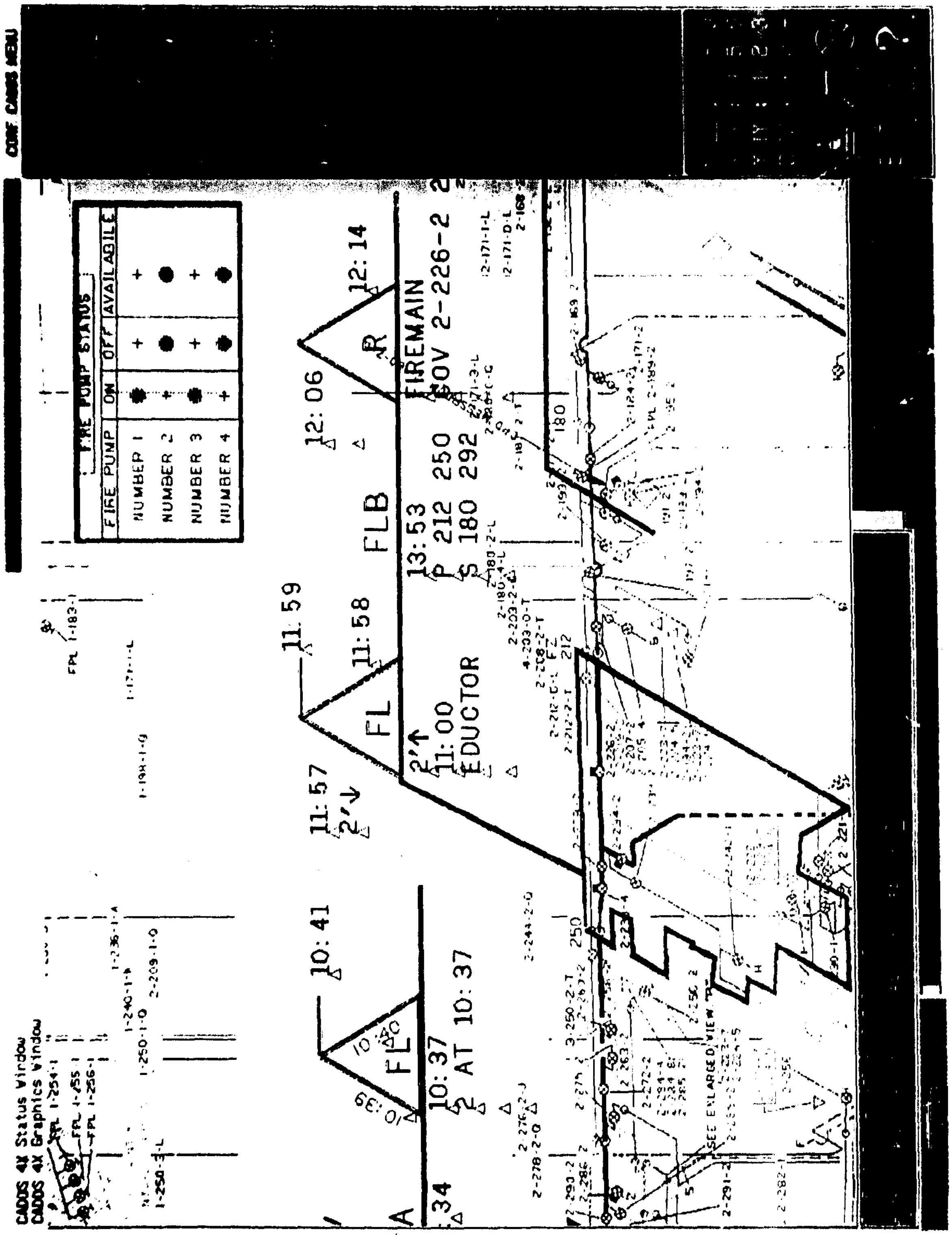


Figure 9 – System Damage Display

Best Available Copy

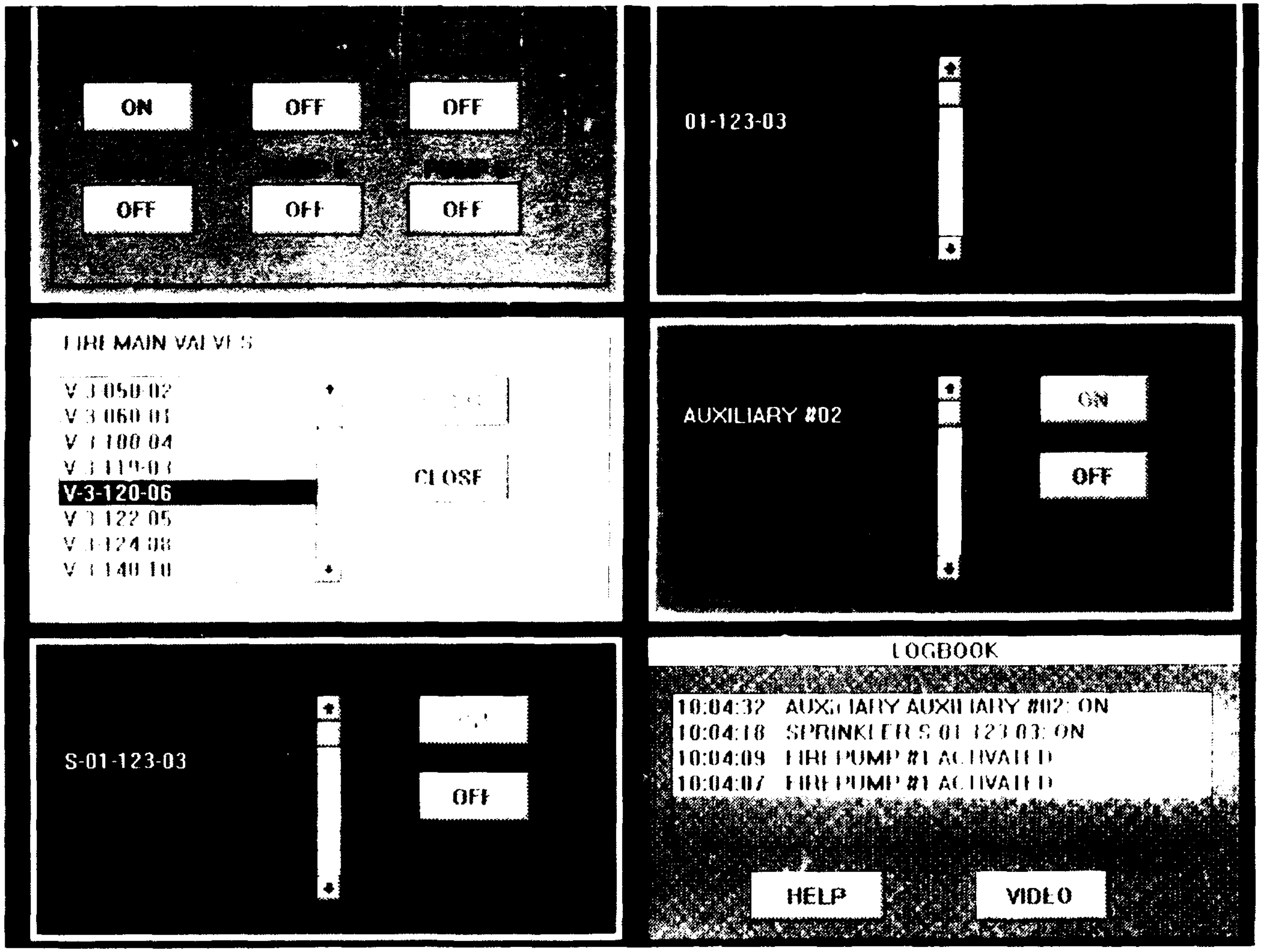


Figure 10 – Control Display

summary damage displays and the detail displays. Damage to any vital system as the result of the fire will be available as a display on the Vital System/DC System Display for that system. Data sources will include the ship's damage control sensors, sensors which are part of the specific system damaged, and investigator's reports.

Stability and flooding: ISMS will be capable of providing stability decision aids. Flooding displays will show the location, approximate size of the hole, flooding boundaries, status and approximate flooding rate on the summary damage displays and the detail displays. The system will keep displays current as the situation changes. Stability displays will provide sufficient information for maneuvering, predicted list and trim for various counterflooding options, and predictions of the effects of continued flooding on stability. See Figure 11. The user will be provided with the stability curves for the actual loading and damaged condition. See Figure 12. In addition, the predamaged design margin curves will be available for comparison.

Ballasting and deballasting control (as required): ISMS will provide the capability to control the ballasting and deballasting operations. ISMS will allow the DCA to accomplish ballasting and deballasting from any workstation.

Vital system/DC system display: ISMS will be capable of providing assistance in reconfiguring vital systems. Displays for vital systems will be the information equivalent of the damage control diagrams for each system from the damage plot. These displays will show equipment status and damage. The displays will also show suggested reconfiguration for specific damage.

Asset Management: This display will show the location of all damage control assets and will maintain the status as assets are moved, used up or destroyed, Figure 13.

Readiness assessment: The ISMS will be capable of providing readiness assessment of all mission areas of the ship. The ISMS will have the capability to use the embedded training data base (deactivation diagrams) to develop this assessment when equipment casualties are reported and entered into the data base.

Embedded training: This will provide an on board training capability which provides the crew with simulated damage and the deactivation effects of the simulated damage. It will provide the training team with a training scenario. During the training simulation, ISMS displays will portray the damage and appropriate damage spread in response to DC actions.

RAD Plot: This will plot the radiation readings taken by the investigators. It will show safe stay times at contaminated battle stations.

Analysis: The analysis software performs operations on the information in the database, and sounds an alarm or provides recommended operational limits based on the results. This software performs the analysis to support all displays including the firefighting, stability and RAD plot displays.

Database: The controlling console or workstation develops and maintains the database and passes updates to the other stations as they occur to ensure that all consoles or workstations have identical databases. Each console or workstation develops displays based on the database it currently stores. The redundant databases prevent loss of data with the loss of one or more consoles. In fact, the system can gracefully degrade so that one or more independent workstations or consoles can continue to operate, after serious damage to the system, using available input data and control capability. When the stations are reconnected, the station in control of each disconnected segment will be able to submit its database to the station in overall control of the rest of the network in order that this data can be incorporated into the system data base. The reconnected stations will receive a data base update upon request.

The database includes stored ship information, data from sensors monitored by the system, damage information, a log of system events to permit retracing casualty actions, inventories and manually entered data. Data entered into the system is immediately available to the DCC console and all workstations.

SOFTWARE REQUIREMENTS

All software will be developed using the ADA computer language. Performance standards will be developed for all analysis software and displays.

ISMS PERFORMANCE

As can be seen from the discussion above, the primary performance improvement is in communications in the form of the time to assemble adequate data required to make a decision and to inform all stations of the required damage control actions to be taken. Surveillance data will appear in DCC as soon as it is measured. Actions taken will be known at all stations as soon as they are entered into the system.

Surveillance will improve due to the broadened coverage of the sensors. This means that the damage control organization will no longer have to wait for the investigator to discover damage, it will be sensed immediately.

The displays will improve information recognition and storage significantly and will reduce the time needed for the repair party leaders and the DCA to assimilate the information, determine alternative courses of action and decide on the appropriate measures.

This improvement in communications, surveillance and displays will reduce the time needed to take action in the most critical period of any casualty: the initiation. The more

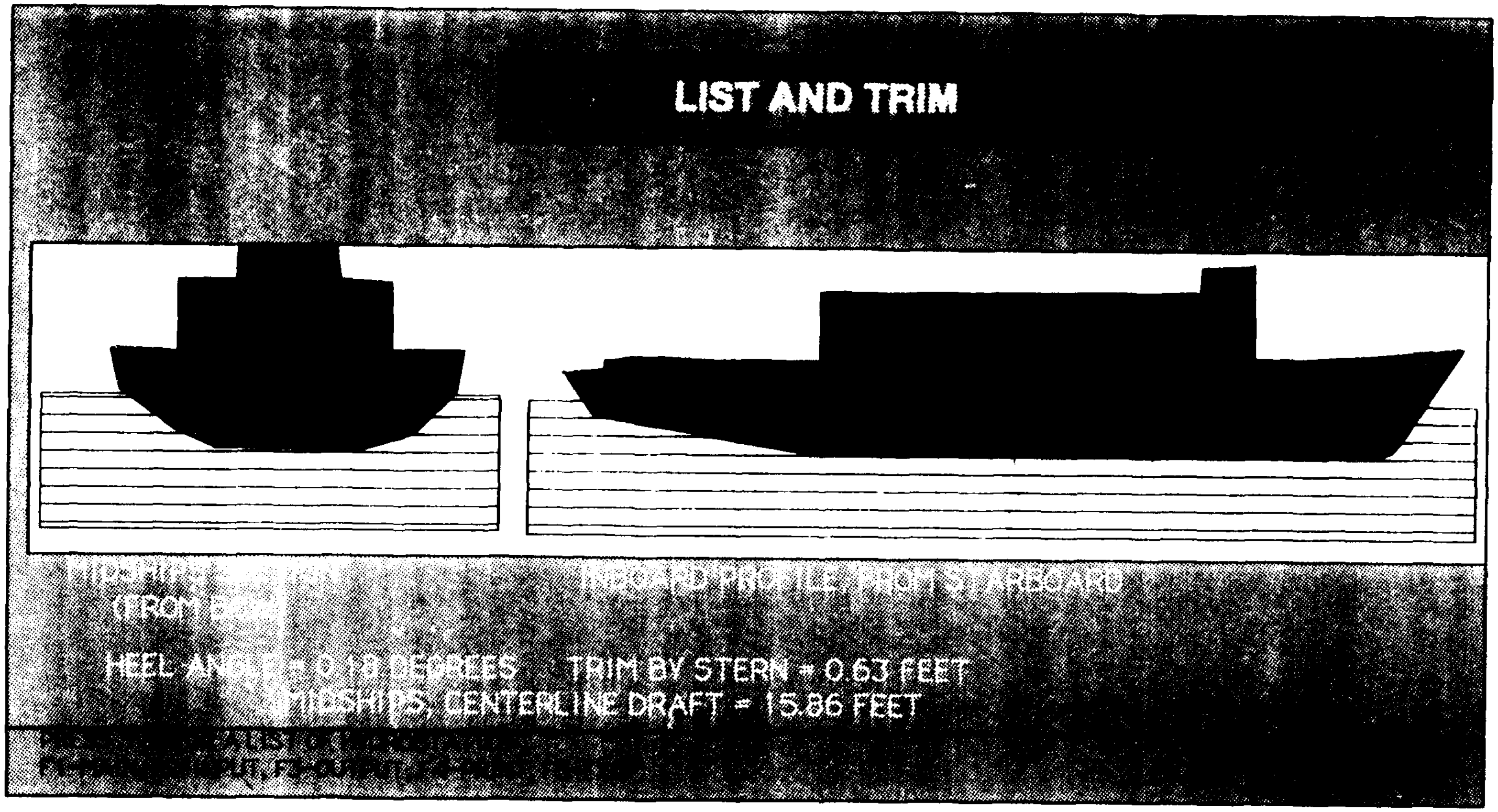


Figure 11 – Ship Attitude Display

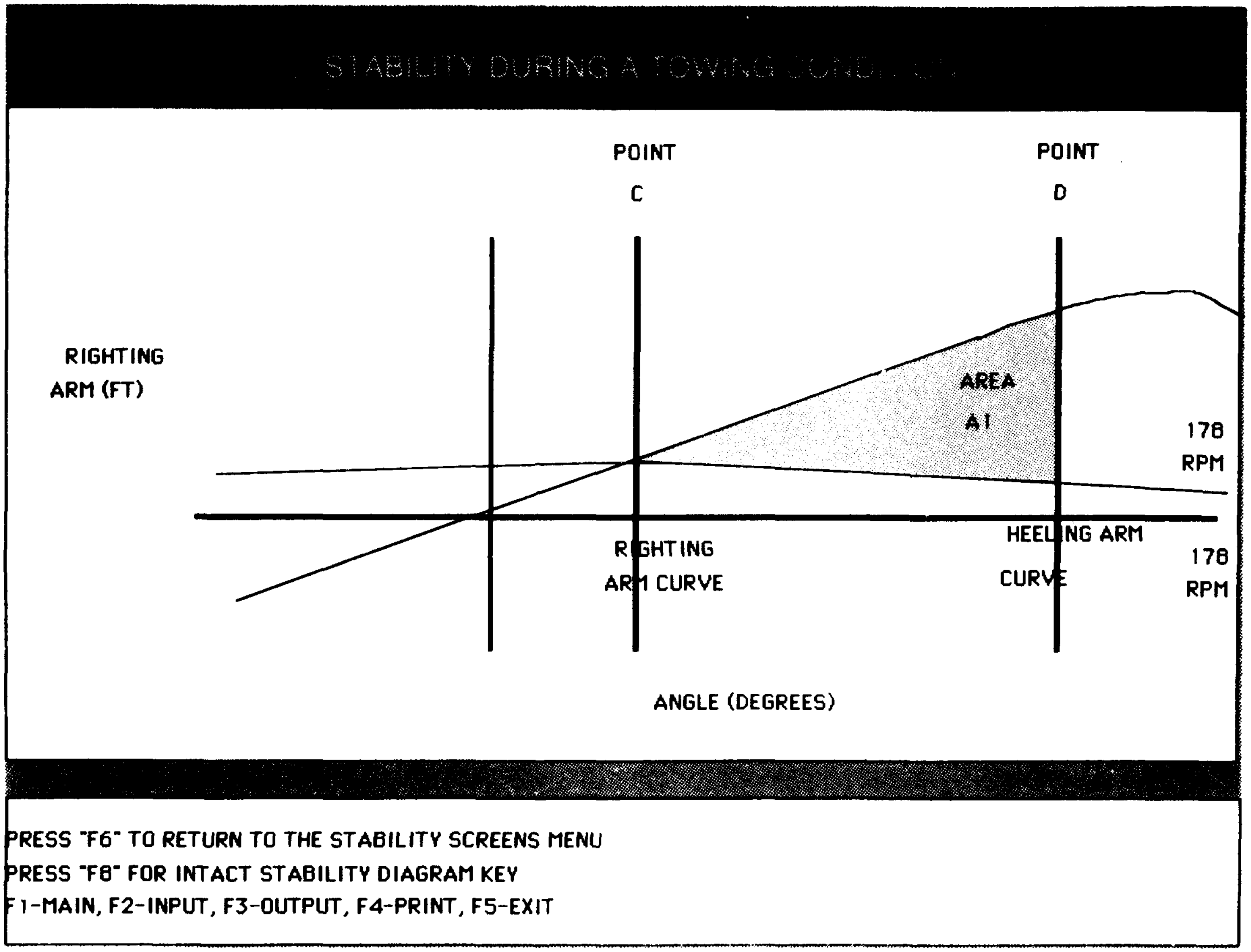


Figure 12 – Ship Stability Curve

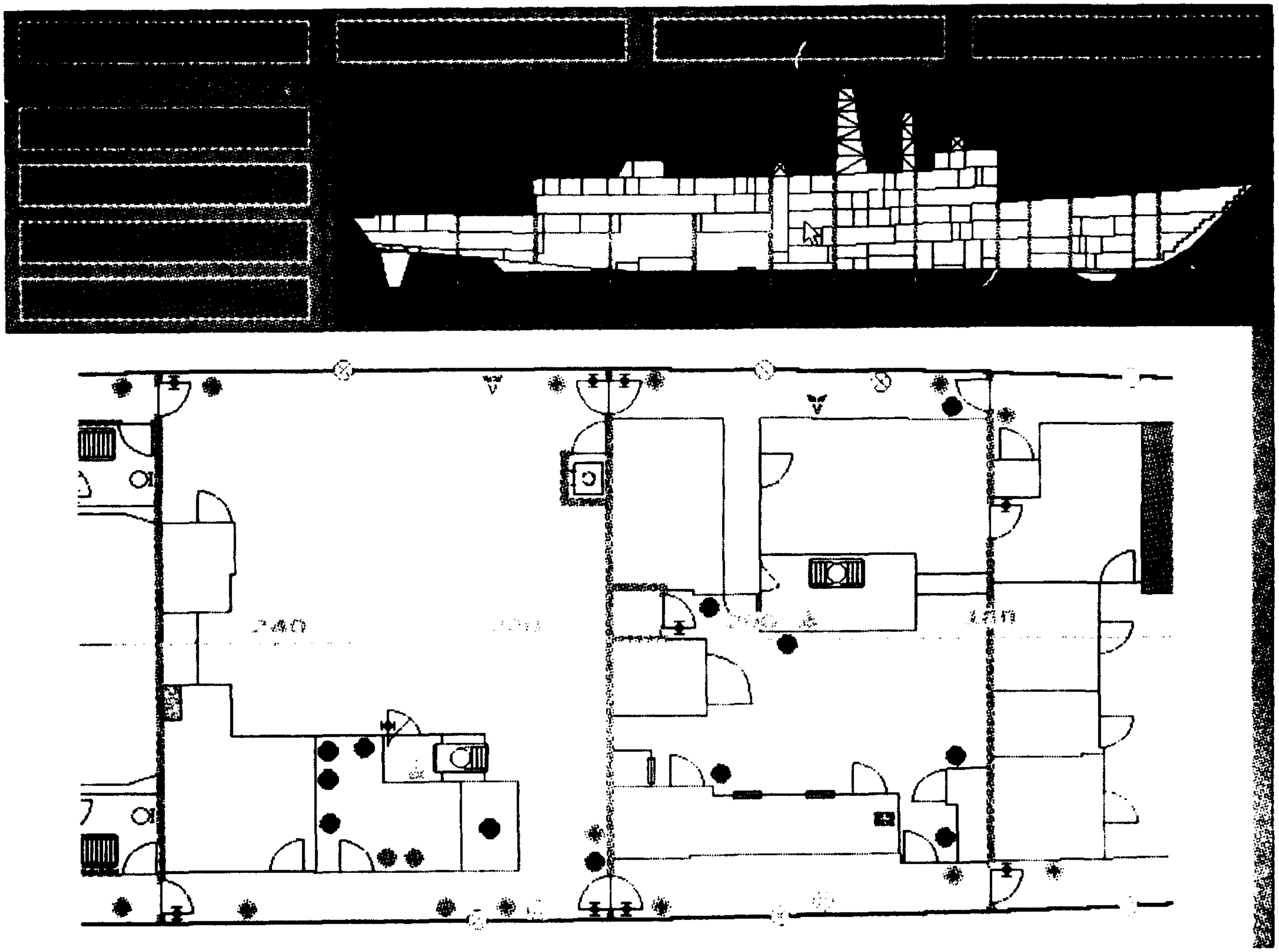


Figure 13 – Assets Display

1. The system must be survivable
2. Multiple terminals are required. Input/output terminals at DCC and the Repair Stations and read only terminals at the bridge and CIC
3. There must be on-scene data communications, system communications must be accurate
4. The system must keep track of compartment data, system data and inoperative fittings. Should recommend isolation strategies.
5. There must be stability evaluation
6. Sensor information should be available if other portions of the system are not delayed
7. Battle damage spare identification, administration and training should be included. These must be common with the Tactical and Operational System.

TABLE 8
FLEET PRIORITIES

quickly action can be taken the more likely it is that a small casualty can be stopped before it runs out of control or a large casualty can be contained and its damage limited. This reduction in response time is illustrated in Figure 14.

The second improvement is in the quality of the information presented. This system will be less error prone than the current method. In addition, the display operators will be able to select the level of detail needed to make assessments and decisions. This will lead to more appropriate responses to casualties, reducing the damage.

These two improvements will lead to improved ship mission readiness after damage. Fewer systems will be damaged by spreading weapons effects, damaged systems will be returned to service faster and the ship will retain more warfighting capability. In addition, since damage will be reduced, the cost, time and resources needed to return the ship to fully ready condition will be reduced.

EARLY FLEET INVOLVEMENT IN THE PROGRAM

ISMS development has been planned to include frequent opportunity for the fleet to have an influence on the requirements. The earliest evaluations of firefighting and stability software were performed aboard ship, and involved the Surface Warfare Officer's School (SWOS). At the November 1991 meeting of the OPNAV Damage Control/Firefighting Working Group an entire two day working session with 20 participants was devoted to ISMS. This session proved extremely successful in exposing the fleet to the system, gaining their interest and obtaining their guidance. The session concentrated on the fleet's priorities for development of the system and a review of the proposed displays. The priorities are shown in Table 8. As currently configured, the Engineering Development Model (EDM) will satisfy these priorities except for training.

Based on the session, the fleet preferred the isometric, multiple deck display of the ship's arrangements similar to those shown on the DC diagrams. This layout gives adequate information and provides an intuitive relationship between the decks and levels. Relationships among casualties and between casualties and compartments can readily be seen. Labeling of the compartments and numbering of the closures, however, provides too much information. This information should be provided on zoom displays or in a window on the screen as required. Similarly, general information about all casualties should be shown on the total ships view, with detail information shown on the zoom displays. The use of color to highlight spaces containing damage control functions, hazardous materials and repair station areas of responsibility was endorsed. A GUI, rather than a menu, should be used to highlight locations and perform other operations.

There is so much information to display that ultimately multiple monitors will be required. The fleet personnel felt that as many as four screens might be needed. Twenty inch monitors were recommended.

Use of video information will be investigated based on fleet input. Locating cameras at key points will aid in assessing the problem and in decision making. Infrared cameras could be used to see through smoke.

The fleet will support the development of analysis software to recommend valves to secure in the event of a rupture, compartments to flood or dewater to maintain stability or where to set fire boundaries. In addition, they recommend that the system maintain a log of events and message traffic.

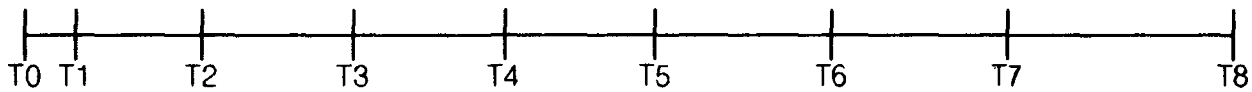
As described below the fleet will continually be involved in the evolution of the system. This will ensure that we field a system which will meet their needs and that the fleet will endorse and support the system when it arrives aboard ship.

ISMS PROGRAM

A pre-Advanced Development Model (ADM) will be installed aboard DDG 51, FFG 7, DD 963 and CG 47 class ships. This will consist of a stand alone unit installed in DCC which will run stability software, a Damage Control Asset Management System (DCAMS), a CCOL management system and an automated repair party manual. The units consist of a 386 computer and a single monitor. The software

ISMS PAYOFF

BASELINE



T0 DAMAGE OCCURS
T1 SENSOR & EQUIPMENT STATUS (SURVIVING ITEMS)
T2 SYSTEM RECONFIGURATION
T3 INVESTIGATORS REPORT/COMPLETE ROUTES
T4 INVESTIGATOR DAMAGE REPORTS RECEIVED
T5 DAMAGE PLOTS COMPLETED
T6 ORDERS TO REPAIR PARTIES
T7 SECONDARY DAMAGE CONTROLLED
T8 PRIMARY DAMAGE CONTAINED

PROPOSED

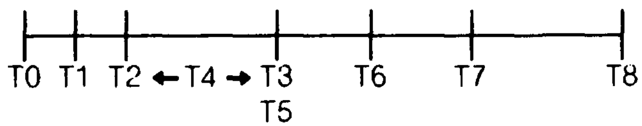


Figure 14 – ISMS Payoff

subroutines are currently written in Fortran, dBase and TurboPascal. Continued Fleet evaluation will be based on standard damage control drills and day to day usage. The results of the evaluation will be folded into the ongoing system development.

The program is currently approaching a Milestone II decision. The ADM is under development. This will be followed by the Full Scale Engineering Development (FSED) phase with continued logistic support planning, specification preparation and testing and evaluation. In parallel, opportunities for backfit and forward fit will be explored, as shown in Figure 15, as will the ongoing initiative to maintain regular fleet interface.

The ADM is being developed at the Naval Surface Warfare Center, Carderock Division, David Taylor Model Basin (NSWCCDDTMB) and at Naval Surface Warfare Center, Carderock Division, Naval Ship Systems Engineering Station (NSWCCDNAVSSES). The ADM hardware consists of SPARCS Workstations connected by local area networks (LANs). A printer and UPS are included. Three workstations will be located at NSWCCDDTMB, three at NSWCPDNAVSSES and one at SWOS. A LAN will link the three workstations together at the laboratories and modem connections will link the three sites. The three workstations will represent consoles at DCC and a repair station and a command center. There will be representative sensors and remotely operated devices to structure development and testing of the software.

The software is being developed at NSWCCDDTMB and will be evaluated at NSWCPDNAVSSES. SWOS will evaluate the software as it is developed and provide continuing input to the development process. The software will include an integrated database containing interactive damage control plates, stability algorithms, DCAMS, CCOL, automated repair party manual and other damage control software. Also included will be sensor, control and interconsole communication software.

The land based testing at NAVSSES will be done with fleet support and will ensure that:

-the sensor and manually input data is entered into the system, evaluated and added to the database;
-the LAN operates correctly linking all stations and observing control protocol requirements;
-the network software keeps all consoles' databases identical and up to date and will gracefully degrade as communication links and consoles are damaged;
-the displays readily depict the situation in the proper level of detail for the operator and that the remote devices can be operated from the consoles through the LAN,
-the anticipated performance improvements have been made.
-reliability and maintainability is satisfactory

The EDM system will be installed aboard the R&D test ship, USS JOHN L. HALL (FFG 32). The software will be identical to that of the landbased test site, however the hardware will be "hardened" versions of the SPARCS workstations. We will install representative sensors and control devices to ensure that there is no impairment of the ship's current system. The shipboard testing will be performed for COMOPTEVFOR who will evaluate the system based on the TEMP requirements.

ISMS is being considered for three new ship designs, DD(V), L(X) and CVN 76. The display software will be identical to, or an improved version, of the EDM display software. The communications software will be tailored to the communication systems installed on the ship. In the production phase on these new ship classes we intend to use hardware consistant with approved combat systems and propulsion systems.

Future ships will be provided the display software as Government Furnished Information (GFI). The specifications developed under this program will describe the requirements for the hardware and for the communications software which will be developed by the shipbuilder.

As the software continues to improve, software modules will be developed and installed on existing systems. It is expected that improved training and administrative software will be developed continually while firefighting software upgrades will be dependent on the state of the art fire algorithms.

INTEGRATED LOGISTICS SUPPORT

Manning: The ISMS will not change the number of people required for firefighting, flooding control or recovery. It will affect the numbers required for communications and management. A significant number of personnel are currently required to man sound powered phones to monitor incoming messages. Since most of these messages will travel on the data communications network fewer personnel should be needed. This, however will be a small decrease relative to the total number of personnel assigned to damage control.

Training: ISMS will result in significant changes in training. PCO, PXO, DCA, repair party leader, team training and other courses will be modified to include use of the consoles, workstations and on scene data entry units. A new ISMS console or workstation operator's course may be needed. Consoles and workstations will be provided to appropriate training sites. One or two Damage Control trainers could be developed which incorporate sensors and portions of controlled systems to provide realistic team training.

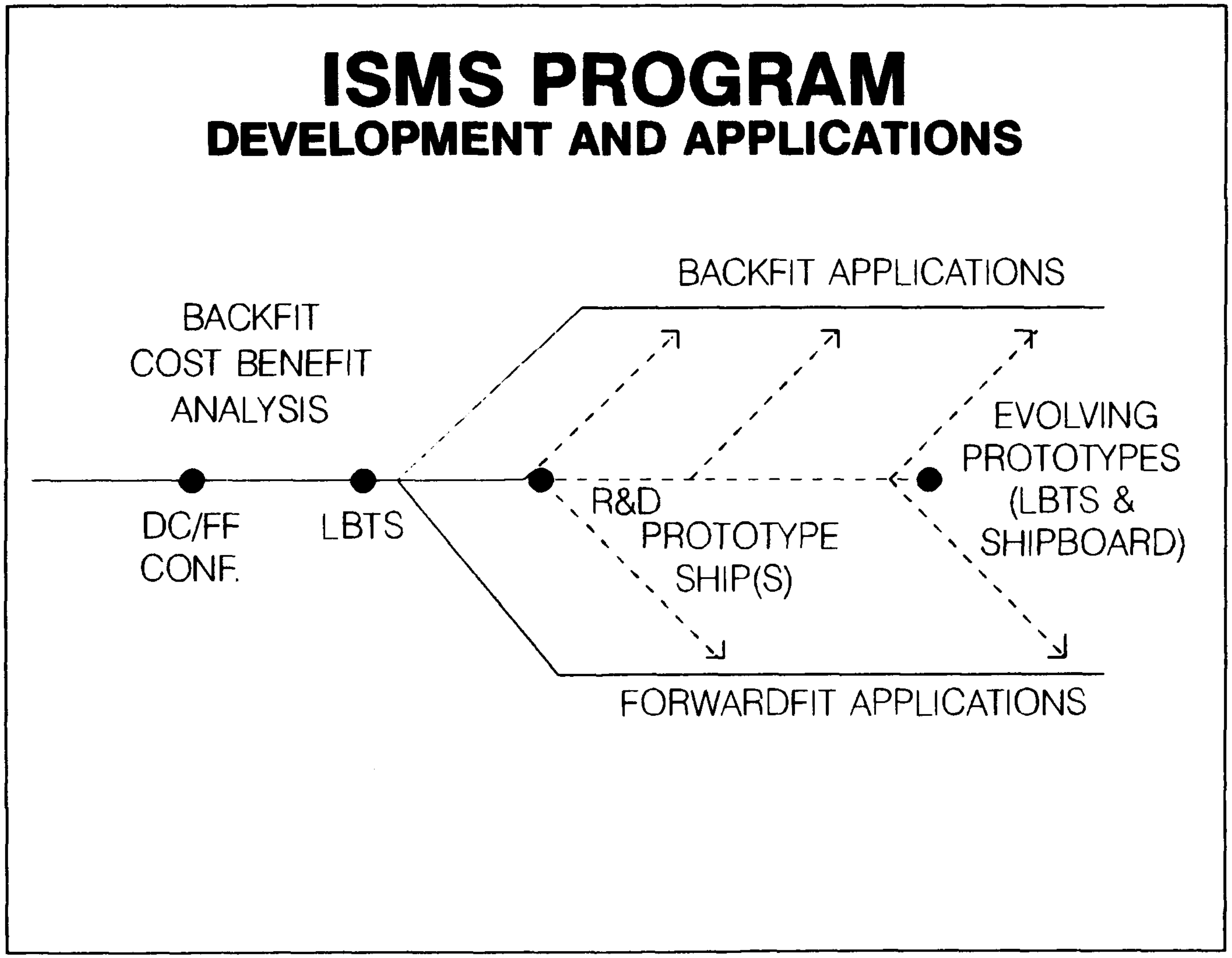


Figure 15 – ISMS Program

RELIABILITY, MAINTAINABILITY AND AVAILABILITY (RM&A)

Reliability: The reliability goal will be established when the ILSP is prepared. The system will be designed for a high reliabilty because it will monitor ship and ship system status during normal and casualty conditions and must be ready at any time to support damage control operations. The system architecture with many redundant elements supports this goal.

Maintainability: The maintainability of the computers, programs and databases must be considered. If the computers are, as currently planned, Contractor Furnished Equipment (CFE), maintainability will be developed by the Contractor based on the requirements in the ship construction contract. The programs will be the property of the government and will be maintained by the Navy. Maintenance of the databases, which will generally require updating after each overhaul, will be managed by the Navy.

Availability: Self diagnosing circuits and by module replacement will be investigated as means of achieveing high reliability.

CONCLUSION

Use of the ISMS, even in the stand-alone mode, will mark a significant change in the ship's ability to control damage. This tool, which will present to the DCA information in a way that will make patterns of damage obvious, speed responses and ensure proper action. Systems incorporating communication among sensors, consoles and controlled devices will demonstrate quantum improvements in planning, decision making and reaction time. A key feature of this program, which will ensure a viable and accepted product, is involvement of the fleet in early stages of the design.

ACKNOWLEDGEMENTS

Joseph Maener

REFERENCES

[1].Integrated Survivability Management System, LX Ship Class DC C3 Feasibility Study (Draft) Sep 91, Naval Sea Systems Command (SEA 55X22)

[2].Tentative Operational Requirement (TOR), Damage Control Management System promulgated 14 Sep 88, issued by CNO ltr 3900 ser 098R/8C550910 of 19 Sep 88 (C)

[3].Development Options Paper for a Damage Control Management System submitted Apr 90, Naval Sea Systems Command (SEA 55X22)

[4].OPNAVINST 9070, Ser 09/8U501139, 23 Sep 88, "Survivability Policy for Surface Ships of the U. S. Navy"

Solving the Combat System Remote Control Problem On The Self Defense Test Ship

LCDR David W. Sanders, USN
Project Officer for SDTS
RAM Program Office
(PMS 420)
Naval Sea Systems Command

JHU/APL co-Authors
Rick York
Phillip H. Temkin
Guy W. Riffle
Stephen L. Scheirey

May 1992

Approved for Public Release
Distribution Unlimited

Abstract

Remote control of complex Self Defense Surface Missile Systems poses challenging system design problems. Typical approaches call for brute force digitization of all system interfaces and high bandwidth communication systems to handle the transmission of serial data streams. The Johns Hopkins University/Applied Physics Laboratory (JHU/APL), through tasking from COMNAVSEASYSCOM RAM Program Office, has developed an approach for remote control of the AN/SWY-2 Self Defense Surface Missile System for use on the Self Defense Test Ship. The approach proves to be less expensive to develop, test, and maintain, while providing greater flexibility for changes and future growth than the brute force approaches. The design makes extensive use of commercial off-the-shelf (COTS) technologies and requires minimal custom hardware design. This paper details background, requirements, and design of the system, which is called the Combat System Remote Control System (CSRCS). Special attention is paid to the application of COTS technologies within the CSRCS.

LIST OF TABLES

LIST OF FIGURES

NOTATIONS/DEFINITIONS/ ABBREVIATIONS

ASM	Antiship Missile
CIWS	Close-in Weapon System
CMTU	Cartridge Magnetic Tape Unit
COMNAVSEASYSCOM	Commander, Naval Sea Systems Command
COTS	Commercial off-the-shelf
CSRCS	Combat System Remote Control System
DDEU	Digital Data Entry Unit
DDI	Digital Display Indicator
DMA	Direct Memory Access
DX	Data Extraction
ECC	Error Correction Code
EPROM	Erasable Reprogrammable Read only Memory
ESM	Electronic Support Measures
GMWS	Guided Missile Weapon System
I/O	Input/Output
IRIG	Inter-range Instrumentation Group
JHU/APL	John Hopkins University/Applied Physics Laboratory
KSR	Keyboard Send and Receive
LAN	Local Area Network
LCIU	Launcher Control Interface Unit
LED	Light Emitting Diode
NSSMS	NATO SEASPARROW Missile System
NWAC	Naval Warfare Assessment Center
PMTC	Pacific Missile Test Center
PPI	Plan Position Indicator
RAM	Rolling Airframe Missile
RCIU	Remote Control Interface Unit
RCP	Remote Control Processor
RF	Radio Frequency
SCSI	Small Computer System Interface

SDSMS	Self Defense Surface Missile System
SDTS	Self Defense Test Ship
SNI	San Nicolas Island
TAS	Target Acquisition System
TCP/IP	Transport Control Protocol/Internet Protocol
TEMP	Test and Evaluation Master Plan
VAB	Variable Action Button
WCP	Weapon Control Panel

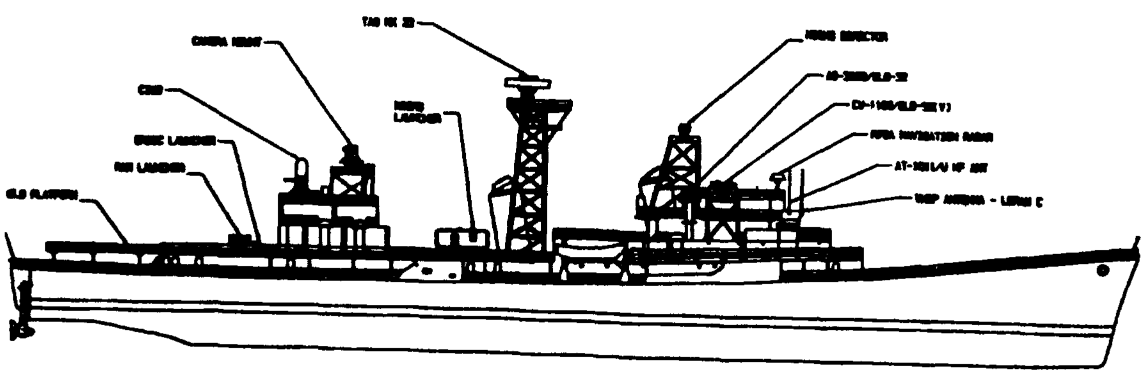
BACKGROUND

Self defense surface missile systems (SDSMS) and close-in Weapon systems (CIWS) employed by the U.S. Navy are a unique breed of weapons used to destroy antiship missiles (ASM). Like the PATRIOT missile system that gained notoriety during OPERATIONS DESERT SHIELD/ STORM, the ship based self defense missile and gun systems must detect, designate, acquire, fire, and destroy high speed incoming ASMs. The scenarios, to which these systems must react, vary greatly from single missile threats; to stream attacks like that experienced by USS STARK (FFG 32); and finally, to high density wave attacks. To verify the effectiveness of these systems the NAVY has developed a requirement to test self defense systems such as PHALANX CIWS, Rolling Airframe Missile (RAM), and NATO SEASPARROW Surface Missile System (NSSMS) to the full extent possible. This poses a problem because of the short range nature of self defense weapon systems. The effective ranges of the majority of these self defense systems restrict the Navy's ability to fully stress these systems against tactical missiles and threat representative target drones without jeopardizing the safety of the crew. Safety constraints have established that no target, either tactical missile or target drone, fly any closer than 5,000 yds to a manned ship. Both the requirement to stress our self defense weapon systems and the constraint to insure safety to the crew has driven the need for an unmanned, self propelled, remotely controlled test platform with remote controlled combat systems on board. These requirements are manifested in the Test and Evaluation Master Plans (TEMP) for the RAM, NSSMS and CIWS.

The U. S. Navy, through the RAM Program Office of the Naval Sea Systems Command, is converting the ex-USS DECATUR (DDG 31) to the Self Defense Test Ship (SDTS) to satisfy the requirement and test constraint. This concept follows a previously successful project used exclusively for PHALANX and GOALKEEPER CIWSs. The project evaluated their effectiveness against tactical missiles, subsonic drone targets, and the supersonic target drone, VANDAL. The complex SDSMSs such as RAM and NATO SEASPARROW require sophisticated remote control systems to manage system operation, ARM/SAFE functions, mode selection, and maintain positive control over the weapon systems and sensors.

JHU/APL has been tasked by the RAM Program Office of NAVSEA to develop the SDTS Combat System Remote Control System (CSRCS) in support of testing the AN/ SWY-2 SDSMS and other systems as they are installed. The AN/SWY-2 SDSMS consists of the integrated Mk 23 Target Acquisition System (TAS), AN/SLQ-32(V)3, and the Mk 31 Mod 0 RAM Guided Missile Weapon System (GMWS). The general objective of the CSRCS is to provide adequate control and monitoring of the TAS radar and RAM GMWS to safely conduct RAM firing exercises on the SDTS from a remote location. Figure 1 illustrates the SDTS configuration with all planned combat system equipment installed. The equipment includes:

1. Mk 23 TAS
2. AN/SLQ-32(V)3 Electronic Support Measures



EX USS DECATUR (EX DDG-31)
SELF DEFENSE TEST SHIP

Figure 1 - SDTS Topside Configuration

(ESM) system

3. Mk 31 Mod 0 RAM GMWS
4. NATO SEASPARROW Missile System (with two directors)
5. PHALANX CIWS with accompanying camera mount

SDTS Concept of Operations

The SDTS will operate at the Pacific Missile Test Center (PMTC) at Point Magu, California, and will be used for both manned and unmanned operations. It will be equipped with two diesel powered outdrives for propulsion, and a diesel powered bow thruster to control heading. During remote operations, the ship will be maneuvered by means of a separate remote control system which is being developed by the Naval Air Warfare Center, Weapons Division. A target barge will be towed about 150 feet astern of the SDTS and will be the actual target for the anti-ship missiles and target drones.

The ship is expected to remain underway on the test range throughout test periods, so it is being outfitted with berthing and messing facilities to accommodate maintenance and test personnel. It will also have an operational helicopter deck to help move people between the ship and control sites.

It is expected that prior to unmanned exercises the onboard test team onboard will make all necessary shipboard preparations for the scheduled event, transfer control to the remote operation sites, and then depart the ship. After the scheduled tests have been completed, they will reboard.

The combat system will be controlled from nearby San Nicolas Island (SNI) via an encrypted RF communications link. The SNI control site is located on a 900-foot cliff overlooking the test range, which will provide line-of-sight operating ranges of 35 to 40 miles. The communications link is being developed by the Naval Warfare Analysis Center (NWAC), Pomona, California.

Overview of AN/SWY-2 System Operation

The AN/SWY-2 SDSMS which will be on SDTS includes several operator control panels which connect to the system using both discrete, hardwired control lines and interprocessor communications.

Operator interface to the RAM system is provided by the Weapon Control Processor (WCP). However, the WCP is more than just a control panel. In addition to a panel of switch/indicators and a LED status display, the WCP also includes one of the RAM system's five distributed processors. Processor functions resident in the WCP include firing logic as well as operator control. Interprocessor communications take place over a 1553 standard data bus.

Data Extraction (DX) from the RAM system is provided by an instrumentation system which is connected to the Launcher Control Interface Unit (LCIU) by an NTDS Type A (MIL-STD-1397C) interface. The DX system is controlled from a separate keyboard, rather than the WCP.

Operation of the TAS is provided by two separate units: the System Status Panel (SSP) and an OJ-194/UYA-4 display console. The SSP is a unit of the TAS which functions as an operator control panel for some of the system hardware functions. It consists of a group of switches and indicators that operate discrete 28 VDC control lines. The interface between the SSP and the TAS Signal Processor is a single cable that comprises this group of control lines. The UYA-4 console interface to the AN/UYK-44 TAS computer is an NTDS Type A interface.

TAS records data from the AN/UYK-44 computer on a USH-26 Cartridge Magnetic Tape Unit (CMTU). The interface between the AN/UYK-44 and the CMTU is also NTDS Type A. Control of the data extract function is provided by a Keyboard Send and Receive unit (KSR), which is connected to the AN/UYK-44 by an RS-232 interface. However, the KSR has no control over the CMTU. Tape handler functions such as rewinding the tape can only be accomplished at the tape handler itself.

The Remote Control Problem

The direct, or brute force, approach to implementing remote control of any system might be to locate a duplicate of each control panel at the remote site, convert all of the interprocessor data and commands into serialized data streams, multiplex those, and transmit them between ship and shore using high bandwidth serial communication links. In the case of the AN/SWY-2 SDSMS several types of control panels and interfaces are involved and the data rate is quite high. Consequently, there are several problems with the direct approach, and so the solution necessarily becomes more complex. The problems mainly involve the transmission of inter-processor communications, the use of system control panels at the remote site, and the control of data extraction.

There are several problems with transmitting processor data using the brute force approach. One is the risk of disrupting timing in interprocessor communications. Multiplexing, demultiplexing, and transmitting the data streams could easily induce latencies that exceed processor interface requirements. Another problem is that this approach does not readily lend itself to error checking and recovery. Error correction coding could be multiplexed onto the data stream, but it would increase overhead. This approach would also require a significant amount of custom hardware to digitize and multiplex all of the data. Finally, handling the high data rate of the multiplexed data would likely require multiple RF communication channels, which would be cumbersome to operate as well as expensive.

The main problem with using actual system control panels is the cost and difficulty of obtaining them. It was a requirement for SDTS that the system be capable of both local and remote operations, so the control panels that are part of the shipboard system were required to remain on the ship. Additional units were required for the remote site. Common control consoles like the OJ-194/UYA-4 are expensive to obtain and operate, and they require a closed loop water system for cooling; but they are generally available. However, control panels such as the TAS SSP and the RAM WCP are unique system modules. It is likely that only one unit per system is built, and there are no spares available. The cost of contracting the manufacturer for a single additional copy of some system unit would likely be prohibitive.

The problems with remote data extraction are functional control and data storage capacity. In order to control the TAS and RAM DX systems, the remote control system would have to interface with the TAS KSR and the RAM DX instrumentation as well as with the other control consoles. Even if it did, though, the TAS CMTU data capacity is inadequate to record enough data for a day's worth of remote testing; so the DX capability would be effectively lost for some portion of the remote operations.

THE SDTS CSRCS APPROACH

The CSRCS design makes use of several fairly simple and common technological building blocks to solve the problems of combat system remote control. Transmission of processor I/O data is accomplished using local area network technology; high speed graphic workstations are used to simulate system control panels, and an integrated data extraction capability is provided using high capacity CMTU technology. Each of these areas is highlighted in the succeeding sections. Figure 2 is a block diagram of the CSRCS.

The central node of the CSRCS is the Remote Control Processor (RCP). Its primary functions are to maintain the system interfaces, provide an integrated data recording capability, and to communicate with the remote site. The RCP is located on the SDTS and connects, either directly or through Remote Control Interface Units (RCIUs), to all of the combat system elements which are to be monitored or controlled by the CSRCS. The RCP also connects to a communication system via an IEEE 802.3 ethernet interface.

The RCIUs, which are being designed and built by NSWSES and General Dynamics for the TAS and RAM systems, respectively, will provide hardware interfaces to the SSP and WCP. The RCIUs will physically interrupt front panel switch circuitry and permit switch states to be set by the

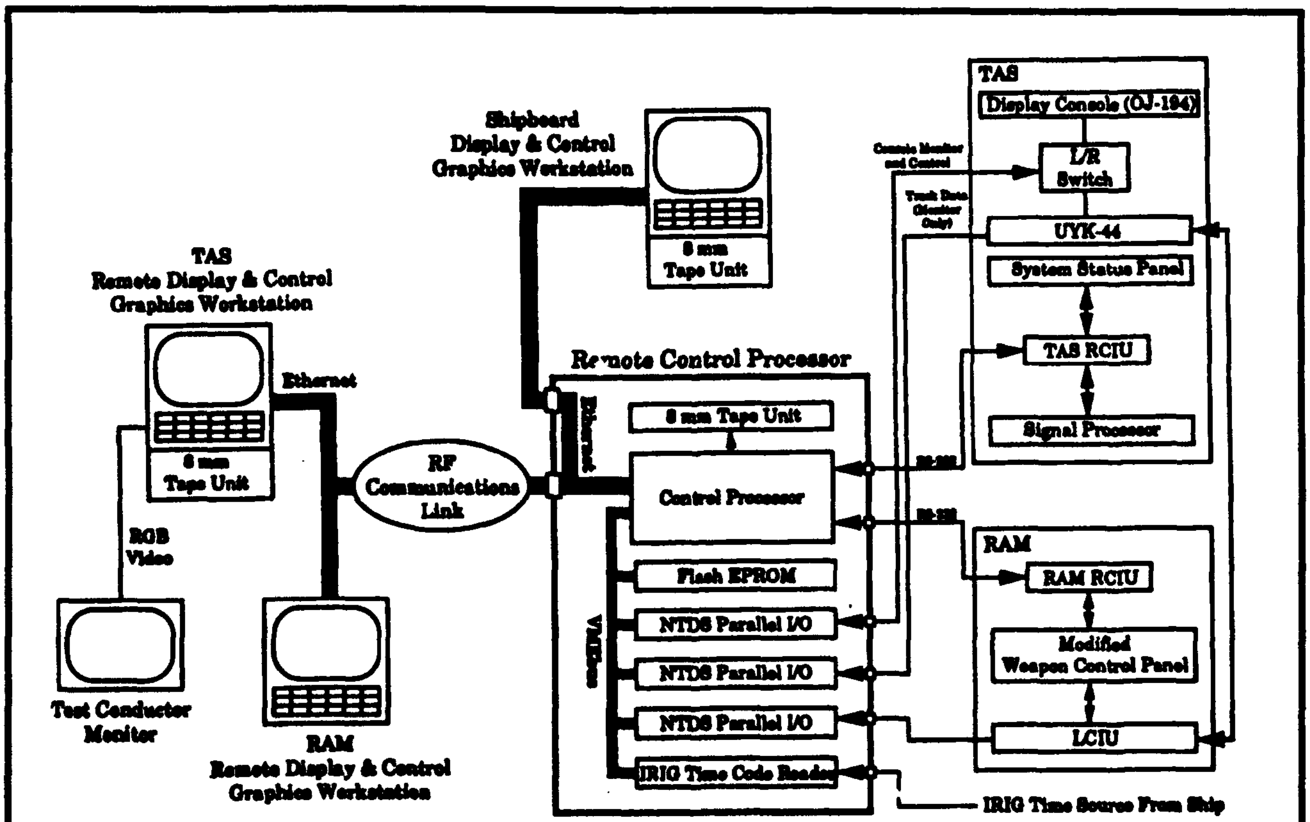


Figure 2 - Self Defense Test Ship Combat System Remote Control System Block Diagram

CSRCS operator. The RCIUs will be controlled via serial interfaces to the RCP.

Display and control functions will be distributed between two graphics workstations located at the control center on San Nicolas Island. One of the workstations will function as the TAS control terminal, and the other will function as the RAM control terminal.

The RCP uses commercial microcomputer system building blocks to provide a real-time processor which meets the requirements of the CSRCS. These blocks are built upon the VMEBus architecture which forms the backbone of the RCP. The VMEBus allows for interprocessor communication and expansion of the system. The MVME147S-1 board labelled "Control Processor" in Figure 2 is the central processor of the RCP. Its on-board peripheral interfaces allow it to communicate with the RCIUs (RS-232 Serial), the communication system (ethernet), and the Exabyte tape unit (Small Computer System Interface (SCSI)). Via the VMEbus, it controls the three NTDS interface boards, the IRIG time code reader board and the flash EPROM board. The Control Processor executes programs which were designed and coded at JHU/APL in the "C" programming language. The programs run in a real-time multi-tasking environment called "vxWorks," which was developed by Wind River Systems, Inc. of Alameda, California. VxWorks provides a software development environment, a real-time, multi-tasking operating system kernel, and a large assortment of software libraries which greatly simplify the development of the RCP's programs.

NTDS interface boards within the RCP provide interfaces to the TAS display, TAS data extraction, and RAM LCIU data extraction ports. The NTDS interface boards are controlled by the Control Processor. The boards are semi-intelligent; i.e., they are able to execute some rudimentary programs which off-load some processing from the Control Processor. In addition, the boards act as Direct Memory Access (DMA) devices with respect to the control processor. When commanded to do so, the boards move data across the VMEbus to or from the Control Processor, thereby relieving the Control Processor of the processing burden of moving the data. The boards generate VMEbus interrupts to the Control Processor in order to indicate the completion of commands.

The TAS display NTDS interface board, under the control of the Control Processor, performs the necessary NTDS interface protocol to cause the TAS computer to transfer data as if it were connected to a real OJ-194 console. The display data is transferred by the NTDS interface board to the control processor which, in turn, transfers it to the TAS display terminal at the remote site to be displayed. Similarly TAS display console responses are transmitted from the display to the Control Processor, which sends them to the TAS computer via the NTDS interface board. In general the Control Processor is not concerned with the contents of the data buffers; it simply sends them to the TAS display terminal to be interpreted.

The TAS data extraction port is very similar. Under the control of the Control Processor, the TAS data extraction NTDS interface board performs the necessary protocol to make the TAS computer believe that it is connected to an actual Navy recording unit. When data is received by the Control Processor it is passed to a tape control task which writes it, along with data extracted from other sources, to the Exabyte tape unit. The data extraction task time tags all data written to tape with system time read from the IRIG-B time code reader board.

At the remote site, the TAS workstation will have ethernet connections to the communication link and the RAM workstation, for which it will also function as a network server. A color monitor will also be located in the control center to provide an additional TAS console display.

The workstation which is used as the TAS terminal primarily simulates the appearance and function of an OJ-194/UYA-4. The workstation and the graphics software that runs on it utilize windows to implement the various features of an actual OJ-194. These windows include a Digital Display Indicator (DDI) window, Plan position Indicator (PPI) window, Variable Action Button (VAB) selection panel, Digital Data Entry Unit (DDEU), and Radar/Range knobs. A window is also provided to simulate the SSP. The other workstation simulates the appearance and function of the RAM WCP. It has windows for operator controls and system status displays. Each workstation has a three-buttoned mouse that allows an operator to interact with the combat systems through a pointing and clicking technique.

In addition to console simulation, the TAS workstation also provides the ability to control the CSRCS itself. Such functions as RCP data extract control, tape downloading to land, and self test functions are controlled through graphical operator interfaces on the workstation.

A third workstation, which will be located on the ship and will be identical to the TAS terminal, will serve as a diagnostic tool and permit "remote" operation of the system onboard the ship. It will have an ethernet connection to the RCP.

The RF link uses commercially available equipment to encrypt and modulate the network traffic for RF transmission. It will transfer data between the RCP and the remote site over an ethernet interface. The characteristics of the link are beyond the scope of this paper.

Application of Local Area Network (LAN) Technology to the CSRCS Communication Problem

LAN technology has been used commercially for intercomputer communications for several years. In particular, computers using the UNIX operating system have used commercially available ethernet hardware together with standard software routines designed to implement accepted communications protocols such as the Internet Protocol (IP). Two recent developments have made it feasible to apply LAN technology to the remote communications problem. One of these developments is the availability of encryption devices and transmitters which allow ethernet to be extended through an RF link rather than a physical connection; and the other is the availability of software to implement the accepted communication protocols in a real-time multiprocessor board environment. Using these developments, it is possible to communicate reliably between a microprocessor board and a stand-alone computer system, such as the display workstations used in the CSRCS, without having to know the lower level workings of the protocols.

In particular, the CSRCS uses the UNIX communication mechanism called a "socket," which is built on the industry standard Transport Control Protocol/Internet Protocol (TCP/IP) to allow communications between the microprocessor board in the RCP and the display and control workstations on both the ship and land sites. In both the microprocessor and graphic workstation environments, a pre-defined series of system calls are made in order to establish the socket connection. Once this is done, a virtual circuit exists between the two points which allows error-free communication. Data can then be exchanged across the socket using simple and well defined input/output subroutine calls to send data to, and receive data from, the UNIX sockets.

The TCP/IP protocol also has the advantages of providing communication that is reliable, homogeneous, and fast. It is reliable because all data is guaranteed to arrive correctly, in the right order, and without duplication. The TCP/IP sockets are homogeneous in that communication takes place among processes without regard to their location on a network or the operating systems through which they function. Communication can occur across the back plane, across an ethernet, or over a combination of networks. For SDTS, an application on a graphic workstation running the UNIX operating system can communicate over a local area network with an application on a MVME147 microprocessor running a real-time operating system (VxWorks). Finally, the TCP/IP sockets provide very fast data rates between the two hosts. Data rates as high as one-half megabytes per second are possible. This exceeds the data transfer requirements for operator interaction with the combat system and for the real-time display of track data, DDI information, and WCP status.

Tests of actual socket communications between a microprocessor board and a UNIX workstation have provided evidence of sufficient bandwidth for the CSRCS application. A summary of throughput measurements for TCP/IP sockets is shown in Table 1. For the results shown, communication was between two MVME147 microprocessors running the VxWorks operating system. Data was sent from one microprocessor to the other and timing statistics kept. The size of the data buffers was varied.

Table 1: Socket Data Rates with TCP/IP Protocol

Block Size (bytes)	Throughput(bytes/sec)
1	2222
256	251803
512	323368
768	390508
1024	538947
2048	568888

Application of Graphic Display Workstations to the CSRCS Console Emulation Problem

To overcome the problems associated with using actual system consoles for remote control, the CSRCS simulates the combat system control panels using commercially available graphic workstations. Graphic workstations are simple to obtain and maintain. They are relatively inexpensive, and they have built-in network interfaces.

Graphic workstations are well suited for use as system control consoles for several reasons. One is that extensive graphical manipulation software libraries are available which greatly simplify the task of console simulation. The graphical interface to the user can be made to present a look and feel very similar to that of the actual consoles. Another is that the modularity of the windowing feature allows for expandability of the system. Additional windows can be created to implement additional operator interfaces. For example, an additional control window on the TAS control workstation simulates and provides an operator interface to the SSP, allowing the one workstation to be used as an SSP as well as an OJ-194.

Finally, the workstations can be used to perform other functions in addition to console simulation. They can also be used as development stations, file servers, debugging aids, and data reduction tools. These additional uses help to reduce the overall cost and development time of the system.

Application of High Capacity Magnetic Tape Cartridge Technology to the CSRCS Data Extraction Problem

The problems of limited data capacity and remote control of data recording devices on the SDTS were overcome by adding a commercial streaming CMTU and associated control and processing software to the RCP. The CMTU has a larger data capacity than units currently used in the system and can be completely controlled through operator control windows on one of the graphic workstations.

Data from the TAS system, RAM system, and RCP operator interactions are tagged with IRIG-B time and are stored on a single, compact tape cartridge. Data can be extracted at rates up to 240 kilobytes per second in physical records that are 48 kilobytes long. It is estimated that a tape cartridge can hold over 48 hours of RCP data, TAS data, and RAM data. RCP tape control provided by the workstation allows multiple files to be placed on a cartridge. Extracted data can be transferred from the RCP to the land-based computer hosting the TAS console emulator. This will allow data to be retrieved immediately following test exercises without waiting for tape cartridge recovery from the ship. It also creates the potential for quick-look data reduction using the graphic workstations.

The RCP tape unit is an EXABYTE Corporation model EXB-8200 CMTU. The EXB-8200 is a high-performance, high-capacity 8mm cartridge tape subsystem that includes an integral SCSI interface. The EXB-8200 uses advanced helical scan technology derived from 8mm video technology, which affords high recording density and data storage capacity. It uses the industry-standard 8mm data cartridge, which is removable, re-writable, and which can store over two gigabytes of formatted user data. The EXB-8200 conforms to the dimensions of the industry standard 5.25-inch form factor, which simplifies its installation.

Helical scan recording offers many advantages over stationary head recording. Advantages include increased recording density, small physical size, gentle tape handling, low power consumption, high reliability, and affordable cost. The helical scanning tape head gives an apparent tape speed of 148 inches per second while the tape is really moving at 0.4 to 0.55 inches per second. This reduces forces on the tape thereby minimizes its wear. Forces required to stop a normal high-speed tape reel are not needed, thus reducing power and associated cooling requirements. Application of advances in video recording technology reduce cost of media and equipment. Low tape forces, reduced power requirements and relations with consumer video technology combine to increase reliability.

The SCSI device contains an integral SCSI controller and formatter electronics, which perform functions normally conducted by the host system. This frees the host for more important work. It also employs read-after-write error checking and automatic rewrite using on-board Error Correction Code (ECC) circuitry, and features a non-recoverable error rate of less than 1 bit in 10^{13} bits. The device provides high-performance asynchronous SCSI bus data transfer rates up to 1.5 megabytes per second.

The RCP data extract control window on the TAS console emulator provides a complement of user commands. The RCP operator is able to mark each extraction with its run name, run number, and additional user comments, which are placed at the start of the file. Any message that crosses an RCP interface can be selected for extraction based on test requirements. Data extractions are started and stopped by the operator. The amount of tape used is displayed in the RCP data extract control window. The operator has the choice of rewinding the tape and recording over old data or forwarding the tape to append data at the end. In this way data from a new test can be placed at the end of an existing tape.

When an exercise is completed, extracted data can be quickly transferred from the RCP tape drive to the land based tape drive, which is connected to the TAS workstation. This feature expedites the retrieval of test data at the end of a test period.

An added advantage of the CSRCS DX capability is that a data reduction capability could easily be added by building on existing features of the graphic workstation and operating system.

CONCLUSION

The design of the SDTS CSRCS provides simple and relatively inexpensive solutions to the complex problems of combat system remote control by making use of modern software design, networking techniques, and commercially available hardware. No new technology was created in the design of the CSRCS. Instead, it is an assembly of fairly simple and common technological building blocks effectively applied to a new problem.

The most significant problems in implementing remote control of the integrated TAS/RAM system for the SDTS involved the transmission of processor I/O data, the use of system control panels for the remote site, and controlling data extraction. Each of these problem areas was overcome by application of commercially available technology.

The use of an ethernet LAN and UNIX TCP/IP sockets in the CSRCS is a simple, cost effective means of solving the complicated problem of remote data transfer. They provide reliable communications at high data rates and at significantly lower cost than customized solutions. Development time and errors are reduced because standard protocols and interfaces are well known and widely used.

The use of commercial graphics workstations as system control consoles eliminate the problems of obtaining and using actual system consoles. They are relatively inexpensive, and are easy to obtain and to maintain. They can perform multiple system functions and at the same time provide a look and feel to the operator that is virtually identical to the actual system control units.

The use of a low-cost, reliable, commercially available cartridge tape unit with associated control and processing software gives the CSRCS a data extraction capability greater than the sum of existing system extract capabilities. The CSRCS data extract system places data from all systems on a compact, high-density tape using a wide variety of operator tape controls. It also provides the ability to quickly retrieve data after an exercise, and provides the foundation of a data reduction and evaluation system.

ISO 9000, GLOBAL STANDARD FOR QUALITY

Ronald Carmichael
Quality Assurance Engineer
Quality Assurance Branch
(SEA 51221)
Naval Sea Systems Command

May 1992

Approved for Public Release
Distribution Unlimited

The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense nor the Department of the Navy

Abstract

MIL-Q-9858, QUALITY PROGRAM REQUIREMENTS, has been the driving force in DoD quality assurance standards for nearly three decades. The International Standards Organization (ISO) 9000 series standards, published in 1987, have dramatically impacted the world's business climate. ISO 9000 is expected to replace the Department of Defense standard MIL-Q-9858A, QUALITY PROGRAM REQUIREMENTS, and MIL-I-45208A, INSPECTION SYSTEM REQUIREMENTS, as the defense industry standard for quality.

The European Community's (EC) movement towards a free market economy required a uniform method to evaluate the quality of suppliers' goods and services to help eliminate trade barriers. The ISO 9000 standard provides a modular system of standards to meet the EC's requirement. With the EC representing the world's largest free market, more than 90 countries have recognized the standard. NATO is currently incorporating the standard into the ALLIED QUALITY ASSURANCE PUBLICATIONS (AQAP) standards. Concurrently, the U.S. Department of Defense (DoD) has proposed changes to the Defense Federal Acquisition Regulations (DFAR) replacing our current standards with the ISO 9000 standard. The ISO standard will have a tremendous impact on U.S. Defense manufacturers. The major advantage to DoD by adopting ISO 9000 will be a more effective use of resources to ensure the purchase of quality products.

It will soon become evident that to remain competitive in the international market, U.S. companies will have a vital need to become certified to the ISO 9000 standard. An indispensable instrument of successful management today is a method to evaluate a supplier's quality system. Defense personnel involved with acquisition need a working knowledge of quality standards and systems. The ISO 9000 standard is management's future control system for industrial and design quality. This paper will introduce the ISO 9000 standard, compare the standard to MIL-Q-9858A and review proposed DoD implementation of the standard. We will also discuss the benefits and issues surrounding the DoD's use of the standard.

LIST OF TABLES & FIGURES

NOTATIONS/DEFINITIONS/ ABBREVIATIONS

ANSI	AMERICAN NATIONAL STANDARDS INSTITUTE
ASQC	AMERICAN SOCIETY FOR QUALITY CONTROL
AQAP	ALLIED QUALITY ASSURANCE PUBLICATION
BS	BRITISH STANDARD
DFAR	DEFENSE FEDERAL ACQUISITION REGULATIONS
DoD	UNITED STATES DEPARTMENT OF DEFENSE
DODISS	DoD INDEX OF SPECIFICATIONS AND STANDARDS
EC	EUROPEAN COMMUNITY
EN	EUROPEAN STANDARD
ISO	INTERNATIONAL STANDARDS ORGANIZATION
NATO	NORTH ATLANTIC TREATY ORGANIZATION
RAB	REGISTRAR ACCREDITATION BOARD

Overview of ISO 9000

In today's market, industries are finding their principal competitors and suppliers include companies headquartered in other countries. Product development and marketing strategies must be global to compete in today's market place.

The quality of products and services continues to grow as an important factor to success within a market. The adoption and recognition of an international quality standard is crucial to providing the necessary assurance to the customer in a global market. The defense industry also requires an efficient method of evaluating a supplier's quality system.

The pressure for an international quality standard led to the International Standards Organization (ISO), in Geneva, Switzerland, to begin working in 1983 on a proposed standard. British Standard, BS 5750, was used as a model for the ISO standard. BS 5750 had evolved from the U.S. DoD defense standards and the NATO AQAP standards. However, unique to BS 5750 was a system of certification of suppliers not addressed by NATO or U. S. standards. The U. S. MIL-Q-9858 standard had introduced quality system management standards as early as 1959, but the British system added requirements for a systematic method for supplier quality system management certification.

The success of the British Standard, in use since the early seventies, and the announcement of the single European market by the end of 1992 highlighted the need for an internationally recognized quality certification system and standards. In 1987 ISO published the 5 standards listed below (Table 1).

ISO 9000	Quality Management and Quality Assurance Standards-Guidelines for Selection and Use
ISO 9001	Quality Systems-Model for Quality Assurance in Design/Development, Production, Installation, and Servicing
ISO 9002	Quality Systems-Model for Quality Assurance in Production and Installation
ISO 9003	Quality Systems-Model for Quality Assurance in Final Inspection and Test
ISO 9004	Quality Management and Quality Systems Elements- Guidelines

List of ISO 9000 series documents
Table [1]

Quality Management and Quality Assurance Standards-Guidelines for Selection and Use, ISO 9000 standard, provides basic definitions and summarizes how to select standards in the series. Quality Management and Quality Systems Elements - Guidelines, ISO 9004 standard, provides guidance for an organization to develop and evaluate its quality program based on the three model systems defined by 9001, 9002, and 9003.

ISO 9001, 9002, and 9003 are intended as contractual documents between the buyer and seller to specify the appropriate quality system model to be employed. ISO 9001 requirements are used to ensure conformance to specified requirements during design, development, production, installation, and servicing. ISO 9002 is used when only production and installation conformance is required to ensure quality. The least detailed model, ISO 9003, requires only conformance of the supplier's final test and inspection system (similar to U.S. MIL-I-45208A).

Shortly after the publication of ISO 9000 through 9004 standards, The EC committee for standardization approved and adopted, without modification, these documents as EN 29000 through 29004 standards. The British standard, BS 5750, was subsequently revised to be technically equivalent to the ISO standard. The EC is expected to evolve into the world's largest free market. What began as an European standard is now becoming the global standard for quality. The American National Standard Institute (ANSI) and the American Society for Quality Control (ASQC) are assuming responsibility for U.S. industry adoption of the standard. ANSI/ASQC have published standards Q90 through Q94 which are technically equivalent to the ISO 9000 series, but incorporate customary American language usage and spelling. Basically, ANSI/ASQC Q90, BS 5750, EN 29000 and ISO 9000 are technically equivalent documents. With the adoption of a uniform standard, the next major step is a systematic method for certifying companies in accordance with ISO 9000. To remain competitive, corporate America is moving towards ISO registration. The American Society for Quality Control is recognized by ANSI (ANSI is the USA's member of ISO) as the U.S. organization responsible for certifying registrars. ASQC established The Registrar Accreditation Board (RAB) to function as the US accreditation body.

ISO 9000 Registration

The EC passed an agreement on July 5, 1989 entitled, "A Global Concept for Certification and Testing - An Instrument to Guarantee Quality Manufactured Products". This agreement provided for a uniform system of certification. By agreement and approval of the EC, each nation implementing the standard has an organization that oversees the process. Since the organization within each country may have a different implementation process, this report will focus on the procedure used in the United States.

With the growing worldwide acceptance of the ISO 9000 standards, customers are relying on third party certification of suppliers' quality systems. Recognizing the need for a U.S. internationally recognized authority for quality assurance and control, ASQC formed the Registrar Accreditation Board (RAB) in 1989.

The RAB's primary responsibility is to certify the competency of registrars. Registrars are companies who employ trained and certified quality auditors. Registrars are then responsible for certifying and reviewing a supplier's quality system to determine compliance to the appropriate ISO standard. A typical certification process includes:

- Supplier's preparation or Pre-assessment by Registrar
- Initial Assessment of Supplier's Quality Manual and Procedures
- Certification Audit
- Report of Audit findings and follow up requirements for certification
- Granting of Certification
- Monitoring/Follow-up Audits to maintain certification

Following the audit process and routine follow up, the Registrar issues the supplier a certificate of conformance. The Registrar can suspend or withdraw the certification if a facility is no longer in compliance with the standards.

By relying on the third party certification, the customer, can reduce the need for costly quality system reviews of suppliers. A supplier who becomes certified demonstrates compliance with internationally accepted quality standards. For the supplier, a certified quality system reduces the time consuming multiple audits by prospective customers. Figure [1] graphically illustrates the relationship between Supplier, Customer, Registrar, and accreditation board.

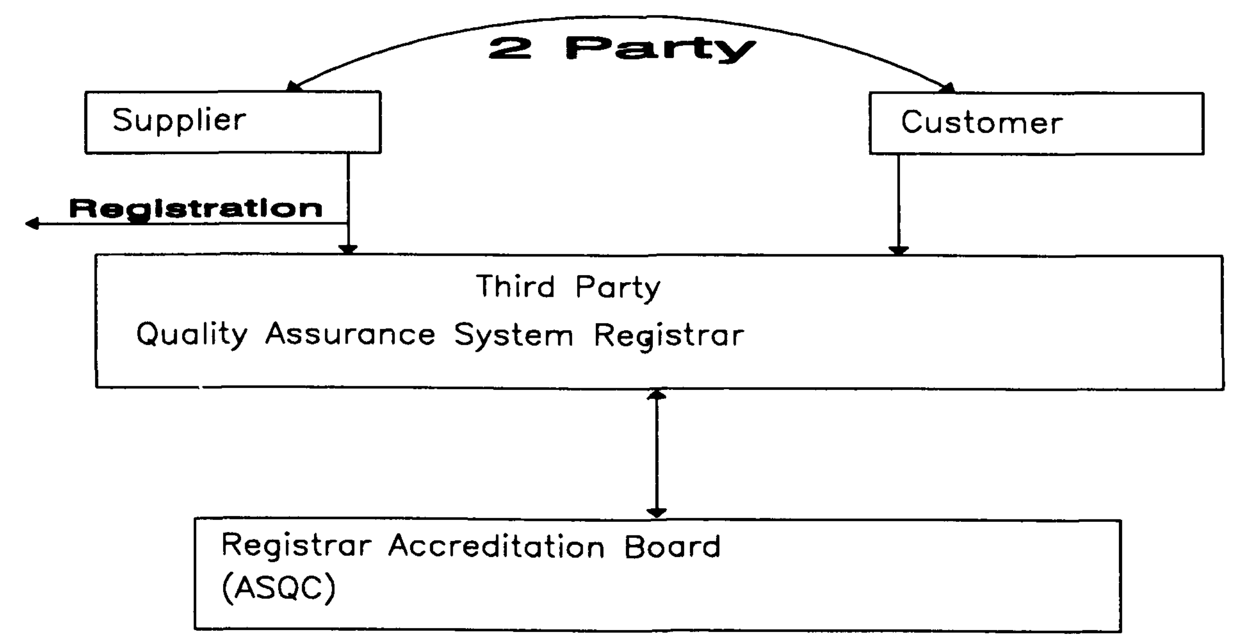
The concept of quality standards and auditing is not new to the Department of Defense. MIL-Q-21549 published in 1958 stated:

"The contractor shall audit the performance of his product quality program in detail. The audit shall be performed on a regularly scheduled basis by an independent audit group or by a team of product quality supervision personnel not having specific line responsibilities in the audit area."

The basic shift from the DoD standards to ISO 9000 will be reliance on the third party auditor and confidence in the accreditation of Registrars. By relying on the third party certification process DoD could avoid duplicating approximately 80 % of the process already reviewed by the ISO certification audits and can focus resources on unique problems and quality issues.

The standard does provide some clear advantages to DoD which include:

- A certified quality system demonstrates compliance with internationally accepted standards, thus simplifying trade practices between NATO allied defense industry members.
- A certified quality system eliminates expensive, time consuming, multiple audits. The result being lower DoD surveillance costs.



Relationship Flow Chart Figure [1]

REQUIREMENT	ISO 9001	MIL-Q-9858A
Management responsibility	·	°
Quality system principles	·	°
Economic/Cost related to quality	-	·
Auditing (Internal)	·	-
Marketing (Contract review)	·	°
Specification and design (design controls)	·	°
Procurement & purchasing	°	·
Production and process control	·	·
Control of production	°	·
Material control, traceability, and identification	·	-
Control of verification status (inspection & test status)	·	·
Production verification (inspection & testing)	°	·
Control of measuring & test equipment	·	·
Control of non-conforming material	·	·
Corrective action	·	·
Handling & post-production activity	·	·
After-sale servicing	·	-
Document & record control	·	°
Quality records	·	°
Personnel & training	·	-
Statistical techniques	°	·
Purchaser supplied product	°	·

KEY Table [2]

· Detailed Requirement ° Less stringent requirement

- Not specifically addressed

ISO 9001 Compared to MIL-Q-9858A
Table [2]

- A certified quality system improves efficiency in production and distribution, thus reducing long term overhead, rework and inspection costs.

It is interesting to note that many companies have multiple government agencies as customers who audit based on different standards. ISO acceptance will standardize government by cutting redundancy and stream line procurement requirements. There are clear advantages for DoD's adoption of the standard. The challenge for DoD will be the implementation and transition from MIL-Q-9858A to the ISO standards.

Comparing ISO 9000 to MIL-Q-9858A

The DoD Quality Assurance Council's memorandum of Feb 7, 1991 approved the adoption of ANSI/ASQC Q90 series standards. Recall, the ANSI/ASQC documents are technically equivalent to ISO 9000 series standards. The memorandum states the documents will be listed in the DoD Index of Specifications and Standards (DODISS).

The detailed proposed plan for DoD's adoption of the ISO standards is outlined below:

- ASNI/ASQC Q91(ISO 9001), Q92(ISO 9002), Q93(ISO 9003) to be adopted in their entirety.
- Standards listed in DODISS
- DoD will not require certification but will recognize it.
- Proposed DFAR changes are in process
- NATO supplement to AQAP documents identifying unique requirements not specified by ISO 9000 series
- DoD MIL-Q-9858A and MIL-I-45208A to be superseded by ASNI/ASQC Q91, Q92, Q93.
- ASNI/ASQC Q90(ISO 9000) and Q94(ISO 9004) will probably be used as guidance documents replacing military handbooks covering MIL-Q-9858A or MIL-I-45208A.

The implementation plan recommends that MIL-Q-9858A and MIL-I-45208A be replaced with the ANSI/ASQC Q90 series standards. To describe the impact on the defense industry, table (2), provides a comparison between MIL-Q-9858A and ISO 9001.

Both ISO 9001 and Mil-Q-9858A have many common features which include:

- Generic requirements which are not specific to product or industry
- Requirements for quality to be designed and built into a product or service
- Periodic management review and commitment to a quality program are required

However, 9001 expands on technical requirements such as design, product identification and traceability, management's commitment, internal quality auditing, service and training. ISO 9001 also clearly states that the responsibility for quality belong to top management. ISO 9001 places more responsibility on the organization's management for the quality of the products and the systems used to produce it. ISO 9001, addresses contract review requirements not specifically covered by MIL-Q-9858A.

While both standards address the requirement for corrective action systems, the implementation philosophy is different. MIL-Q-9858A focuses on the analysis and evaluation of defect trends as the method for corrective action. ISO 9001 emphasizes preventing the reoccurrence of non-conforming products. Total quality management principles and statistical quality control techniques are useful in preventing non-conformance from occurring. Total quality management suggests that we must identify and review the processes in order to prevent non-conforming products and services. The ISO 9000 series standards provide a model for development of a quality system and continuous process improvement.

A major difference between the standards involves the requirement for measuring and testing equipment. MIL-Q-9858A requires and specifies the use of MIL-STD-45662, Calibration System Requirements, by the contractor. ISO 9001's requirement is very general and relies on nationally recognized standards. This will require the DoD engineering community to clearly communicate to the contracting community the MIL-Q-9858A requirements which may still be valid. *Standards or requirements like*, MIL-STD-45662, must be clearly stated in the contract or a DoD supplement to ISO 9001.

The ISO 9000 documents will serve as a valuable base line for developing and establishing defense industry specific requirements. Careful review, by the technical community, is important for successful ISO 9000 implementation. It will be critical for DoD organizations to have supplemental requirement documents to ensure that details, like MIL-STD-45662, are not over looked by the acquisition process. The discrepancies between MIL-Q-9858A and ISO 9000 have to be clarified before DoD transition to ISO 9000 can be completed.

ISO 9000 within DoD

Since each supplier to DoD is unique and has it own set of problems and challenges, there is no single best way for an organization to implement the ISO 9000 standard. The "cook book" or "check list" approach common with MIL-Q-9858A will not work well with the ISO 9000 documents. The Defense Logistics Agency's In-Plant Quality Evaluation program is attempting to move away from "check list" standards for monitoring quality. The ISO documents are designed for flexibility and are not industry specific. The technical community must consider industry specific requirements when establishing quality requirements. The ISO 9000 standards are more user friendly than the current standards. This flexibility, if applied with sound engineering judgement, can improve the communication process between DoD and its suppliers. ISO 9000 can provide a strong foundation for a supplier's quality system.

The design community can no longer simply "produce" the design and view quality as the responsibility of contract administration. The reliance on a manufacturer's quality system must involve the product engineer's work to identify which process steps should be monitored and controlled to ensure quality.

Earlier we established the advantages of the ISO 9000 standard and the forces pushing for acceptance. However, implementation will require time, and management's commitment to a defense industry quality standardization. Obstacles to the ISO 9000 acceptance include:

- Short term cost of implementation (to contractor and indirect government costs)
- Acceptability of third-party audits
- Security
- Reconciliation of requirements with the current standards

In addition, the general inertia to change and the nature of the long-term relationship between DoD and its suppliers will require time for transition. Major procurement last for decades. This will require "grandfathering" of MIL-Q-9858A for several years. It is unlikely the government will pay the cost of a proven supplier to change from the current standard to an ISO 9000 system. However, DoD procurement agencies should consider allowing contractor's to substitute an ISO 9000 based system for MIL-Q-9858A or MIL-I-45208A system at no additional cost to the government. By allowing the ISO 9000 based system the contractor will not have the potential problem of operating a system which complies to both military and industry standards.

Several DoD suppliers are already adjusting their quality control systems to comply with ISO 9000 system to meet the needs of the global market. Accepting the ISO 9000 system could save money by not requiring the contractor to maintain a system which complies with both standards. Requiring third-party audits immediately could place a large burden on small businesses whose only customer is DoD. Gradual acceptance of third-party audits is more likely.

Industry forces will probably drive the transition to ISO 9000 for the following reasons:

- The series provides a "road map" to improvement of business operations and quality.
- Economic conditions may hasten adoption of third-party audits in order to reduce costs.

- Conformance to ISO 9000 will be required to compete in the global market.
- The process of certification can take one to two years. Contractors who start the process early will have a competitive advantage.

Designing a Total Quality System

Don't expect ISO 9000 registration to solve quality problems. It is simply one of the essential tools required for quality improvement. The ISO standard is a baseline for good business practices and continuous quality improvement efforts. ISO 9000 provides the foundation upon which to build industry and technology specific requirements.

What began as an EC standard to improve trade is now becoming the global standard for quality. ISO 9000's success within the U.S. defense industry requires top government and industry management's support and cooperation. Many of ISO 9000's concepts are not new and are similar to MIL-Q-9858A. ISO 9000 standards should be allowed to compliment existing quality systems by using it as a model for quality improvement.

The world wide pressure to adopt the ISO 9000 standard may cause some organizations to loose sight of the standard's objective for quality system management. ISO 9000 is not a "quick fix" to the problems previously attributed to MIL-Q-9858A. Management should encourage a systematic method for quality improvement, and ISO 9000 can serve as management's model for a quality system.

LIST OF REFERENCES

Bradely, R. and Garner, C. "Requiem For MIL-"Q"?". Manufacturing & Quality News, 1991.

Burr, John. "The Future Necessity". Quality Progress, June 1990, p.21

Chirillo, L. "TQM? Inconceivable in Most Shipyards". Naval Engineers Journal, January 1992.

Dyczkowsky, Bohdan. Interview. Quality Practitioners Inc. Mississauga, Ontario.

Lofgren, G. " Quality Systems Registration". Quality Progress, May 1991, pp 35 - 37.

Marsh, A.G. "An Introduction to Quality Assurance in Shipping". The Nautical Institute, 1991.

"ISO 9000 Overview". Stat-A-Matrix Seminar, Inc. 1991

Stratton, John. "What is the registrar Accreditation Board". Quality Progress, January 1992 p 67 - 69.

LOGISTICS READINESS REVIEW TEMPLATES: A Tool for the Program Manager

David T. Conley
Director
Logistics Certification Office
(SEA-04)
Naval Sea Systems Command

May 1992

Approved for Public Release
Distribution Unlimited

The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense nor the Department of the Navy.

Abstract

Recent improvements to the Logistics Readiness Review (LRR) process have the potential to significantly improve the logistics planning process. The logistics knowledge base assembled by SEA-04 and functional matter experts, in addition to defining logistics tasks and milestones, includes systems engineering, budgeting, contracting and work progressing tasks.

The generic LRR templates, which provide estimated task durations and interdependencies for a notional weapon system acquisition program, can be quickly tailored to produce a program specific Program Master Plan (PMP). The PMP, upon approval, becomes the baseline plan for execution and for assessing program progress.

LIST OF FIGURES

ABBREVIATIONS

ACAT	Acquisition Category
CDR	Critical Design Review
CRLCMP	Computer Resource Life Cycle Management Plan
DOD	Department of Defense
ILS	Integrated Logistics Support
LORA	Level of Repair Analysis
LRFP	Logistics Requirements Funding Plan
LRG	Logistics Review Group (OP432)
LRR	Logistics Readiness Review (SEA04L)
NDI	Non-Developmental Item
NTP	Navy Training Plan
PD	Position Description
PM	Program Manager
PMP	Program Master Plan
TEMP	Test and Evaluation Master Plan
TQL	Total Quality Leadership
TRS	Technical Repair Standard

BACKGROUND

NAVSEA's mission is to transform military requirements, as stated in a Mission Needs Statement, into a reliable, affordable and supportable weapon system. As the weapon system progresses through the systems engineering development process, the logistics support elements are also being developed and tested. Prior to each acquisition milestone the program is assessed for logistics supportability in accordance with DOD Instruction 5000.2 of 23 February 1991; "....integrated logistic support progress of the preceding phase and the plans for the following phase will be addressed at each milestone decision point." For Acquisition Category (ACAT) I and II programs, this independent logistics assessment is accomplished by the Logistics Review Group (LRG) administered by OP-432. For NAVSEA ACAT III and IV programs the independent logistics assessment is accomplished by the Logistics Readiness Review (LRR) team administered by SEA-04L.

PROBLEMS DEFINED

The NAVSEA LRR team has reviewed approximately 250 acquisition programs over the past nine years. An analysis of the logistics findings from these reviews highlights the fact that many programs experienced the same, or similar, problems. An effort was undertaken to diagnose the statistically significant logistics problems and prescribe a remedy to these recurring problems. The problems defined below are a result of that analysis.

1) Lack of Planning - The Program Manager (PM) did not have detailed logistics plans, or documentation that indicated logistics planning had taken place.

2) Conflicting Plans - The PM generated and maintained multiple program, acquisition, logistics and funding plans. Many of these plans presented conflicting schedules.

3) Non-Integrated ILS Plans - Closely related to the schedule problem above, but so significant that it deserves to be addressed separately, is the issue of non-integrated ILS planning. It is important to understand that the ILS element plans are very focused. They address the specific ILS element. The individual ILS element plans do not address interrelationships or dependencies with other ILS elements. Nor, do the plans address how the ILS element relates to the system engineering process. This is significant because it is the systems engineering process that generates the source information for most of the logistics products.

Two examples will illustrate these interrelationships:

First - The importance of the Critical Design Review (CDR) and the data deliverables necessary to support the CDR were seldom addressed. The review of product drawings and other design documents by the Program Manager, the systems engineer, the technical design agent, the in-service engineering agent and the logistician prior to the CDR is important for a meaningful and productive CDR.

Second - While the interrelationship and dependence of the Level of Repair Analysis (LORA) on the development of the repair parts lists was usually addressed, the relationship between the LORA and Technical Repair Standards (TRS) was not.

4) Inadequate LRFP - The Logistics Requirements Funding Plan (LRFP) did not track tasks to be performed, or products to be delivered. There was little to no correlation between the ILS plans and the detailed LRFP.

ROOT CAUSES OF PROBLEMS

After defining the problems, we asked ourselves the questions, "Why did this occur?" and "What are the root causes for this problem to occur time after time?"

1) Lack of Planning - There are two basic reasons for lack of planning. First, many PM's are not allowed enough time to accomplish proper planning AND obligate the program funds. Corporately, we place more emphasis on obligation rates than on adequate ILS planning. Second, many PMs lack a properly trained professional logistics staff.

2) Conflicting Plans - Current DOD and Navy policy requires more than 50 separate acquisition and related ILS plans be developed and maintained consistent; configuration management plans, technical manual plans, technical data plans, supply support plans, training plans, test and evaluation plans, safety plans, quality plans, etc., etc. Each plan includes a schedule of tasks to be accomplished and key program events. More often than not, each plan portrays a different program schedule. There are as many different schedules as there are plans. The multitude of different schedules is understandable if one considers that the plans are generated at different points in time, by different support personnel, each with a different perspective and understanding of the acquisition process. It is fair to say that the multitude of plans and schedules cause confusion, and added expense, to both the Program Manager and the logistics review team.

3) Non-Integrated ILS Plans - NAVSEA has developed specialists over the years; specialists in supply support, technical manuals, training course development, safety, reliability, depot maintenance, transportation and mission critical computer resources, to mention a few. Each specialist is narrowly focuses on the particular logistics element described by the specialists position description (PD) and the organizational responsibilities of the sub-group to which the specialist belongs. When specialists venture outside the defined envelope, questions arise relative to ownership of turf. People get very protective and combative when 'outsiders' ventures onto their turf. The specialists adapted quickly to this environment and learned to stay in their own backyard. They have accordingly adopted the safe approach of addressing only their functional specialty.

In addition, organizational barriers exist in many acquisition program offices. The systems engineers and the logisticians are placed in separate subsets of the organization. Organizational barriers to a free exchange of program information are often tolerated. The systems engineers 'do their thing' and the logisticians 'do their thing', oblivious to the others needs.

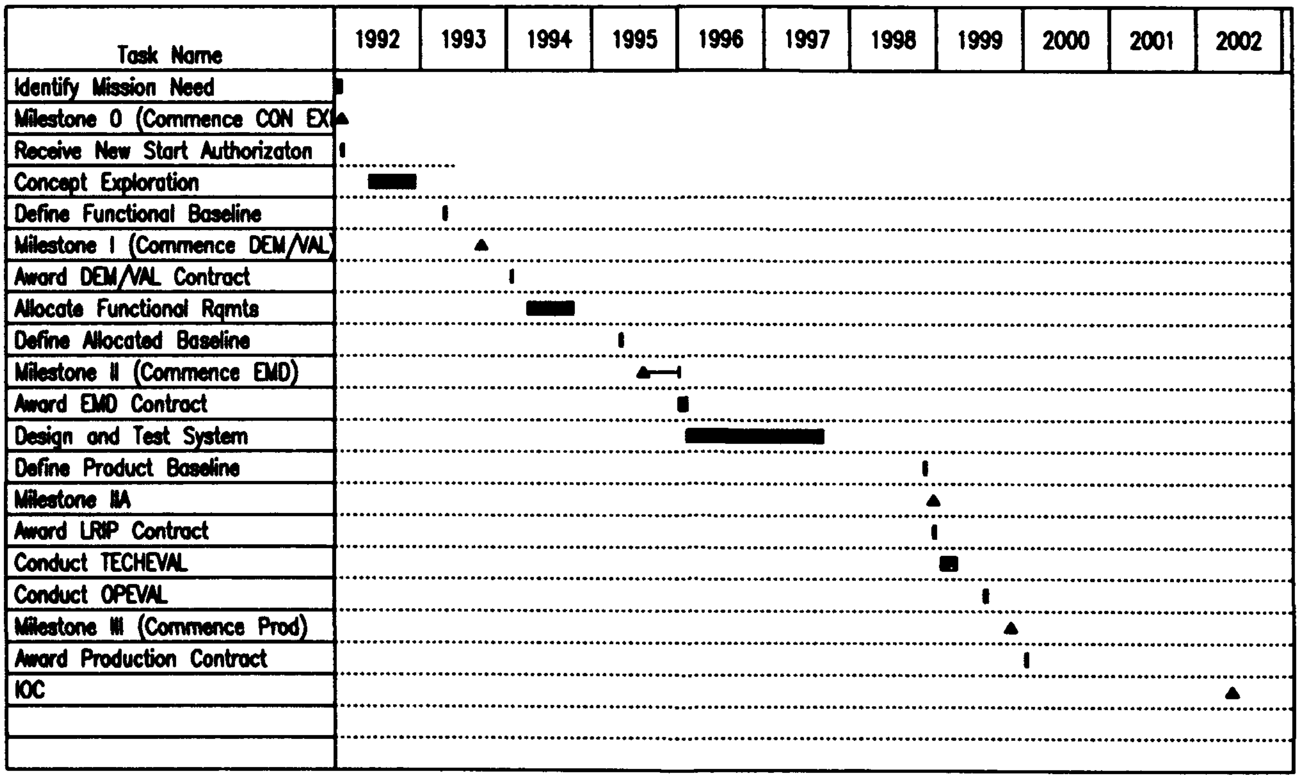
4) Inadequate LRFP - An inadequate LRFP is a direct consequence of inadequate logistics planning. Without a comprehensive, integrated ILS plan it is almost impossible to develop a meaningful life-time cost estimate. The ILS plan forms the basis for the life-time cost estimate. Without a detailed bottoms-up cost estimate for each ILS task and each ILS product over the life of the program, the Program Manager is at risk of introducing the weapon system into the Fleet without proper financial support. In addition, without the detailed life-time cost estimate, the acquisition decision-maker does not have all the facts to answer the affordability question.

SOLUTIONS

As we were analyzing the logistics findings and defining root causes, we were also reflecting on how we conducted the logistics review business. As expected, we found that the LRG/LRR teams suffered from many of the same problems as the program office logisticians. The LRG/LRR team members are ILS element specialists and suffer from the same single dimensional, non-integrated perspective. For example, supply support planning, Level of Repair Analysis (LORA), technical manual planning and planning for the training program are under the purview of four different review team members. The ILS plans are reviewed as separate, non-integrated elements using single dimensional check-lists.

KEY PROGRAM EVENTS

Figure 1



To overcome the very narrowly focused, single dimensional reviews, SEA-04L, assisted by subject matter experts, developed vertically integrated ILS element templates by adding the dimensions of time and dependency to the flat check-lists. The dimension of time is necessary to assess the probability of an action being complete, or a product being delivered by the need date. The dimension of dependency speaks to predecessor and successor tasks (inputs and outputs), and facilitates the review of interfaces between ILS elements and the systems engineering process. The defining of predecessor and successor tasks also facilitates horizontal integration of the ILS element templates.

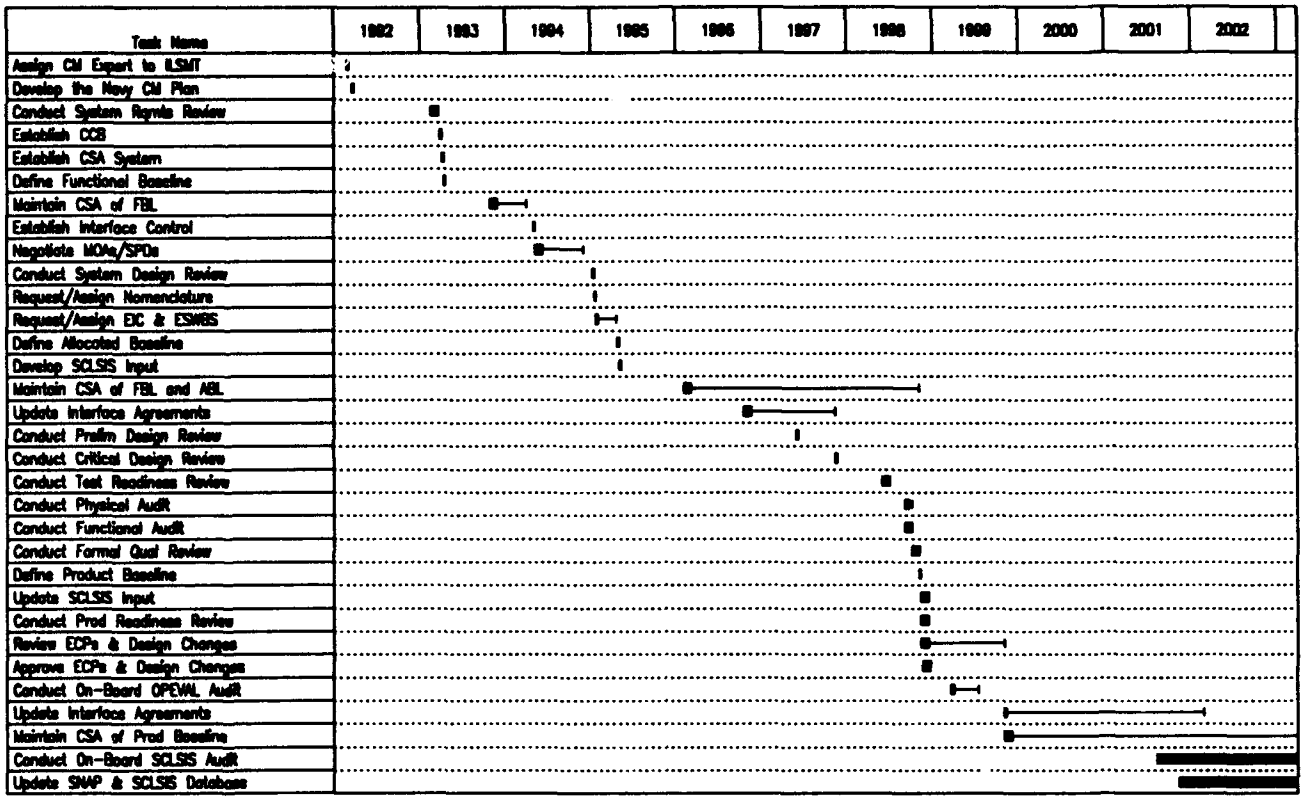
A key program event template per DOD Instruction 5000.1 was

identified as a framework prior to developing each ILS element template. (See Figure 1) After each ILS element template was developed, the element template was horizontally integrated into a master logistics network. (See examples, Figures 2, 3 & 4) Dependent tasks were joined to form a logical sequence of tasks and events that graphically depicted the integrated logistics planning, acquisition and support process. By adding the dimensions of time and dependency, a more complete and accurate 'yardstick' to measure the logistics health of the acquisition programs was created.

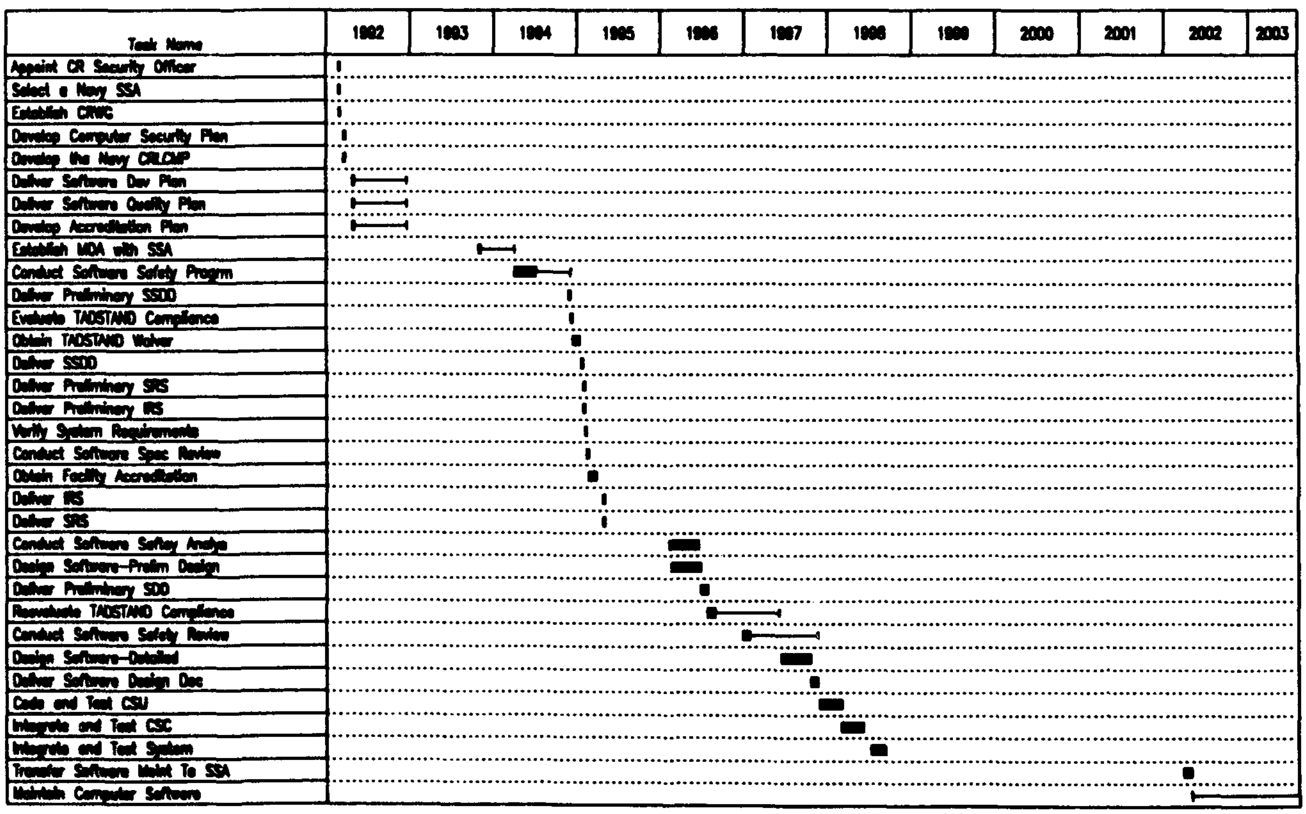
Having developed a master logistics network, it was a small step to add several systems engineering tasks, contracting tasks, budget and funding tasks, and key program milestones. (See Figure 5) What resulted was a generic Program Master Plan (PMP) that included all the elements necessary to plan or assess an acquisition program.

With feedback from Program Managers the PMP will improve over time. This weapon system acquisition process model will be continuously updated and improved, in accordance with Total Quality Leadership (TQL) methodology.

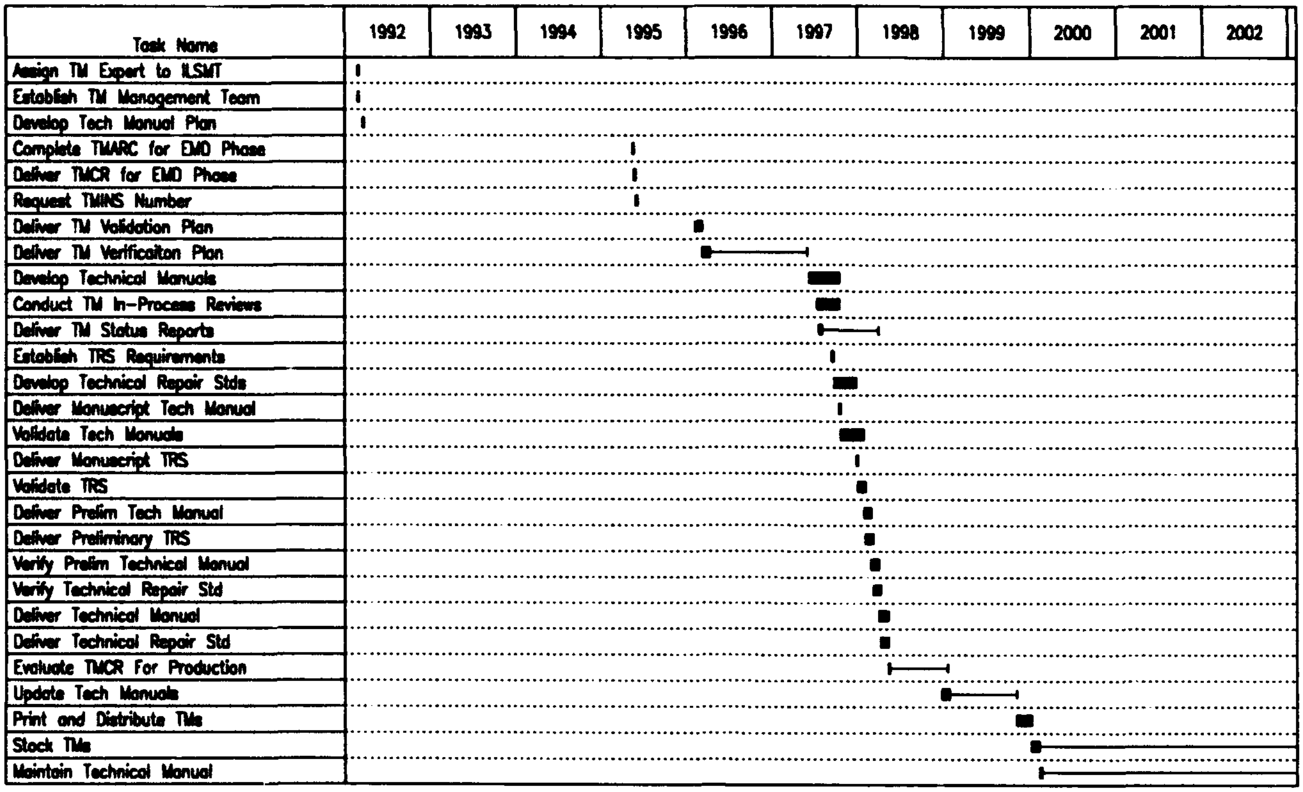
CONFIGURATION MANAGEMENT PLAN
Figure 2



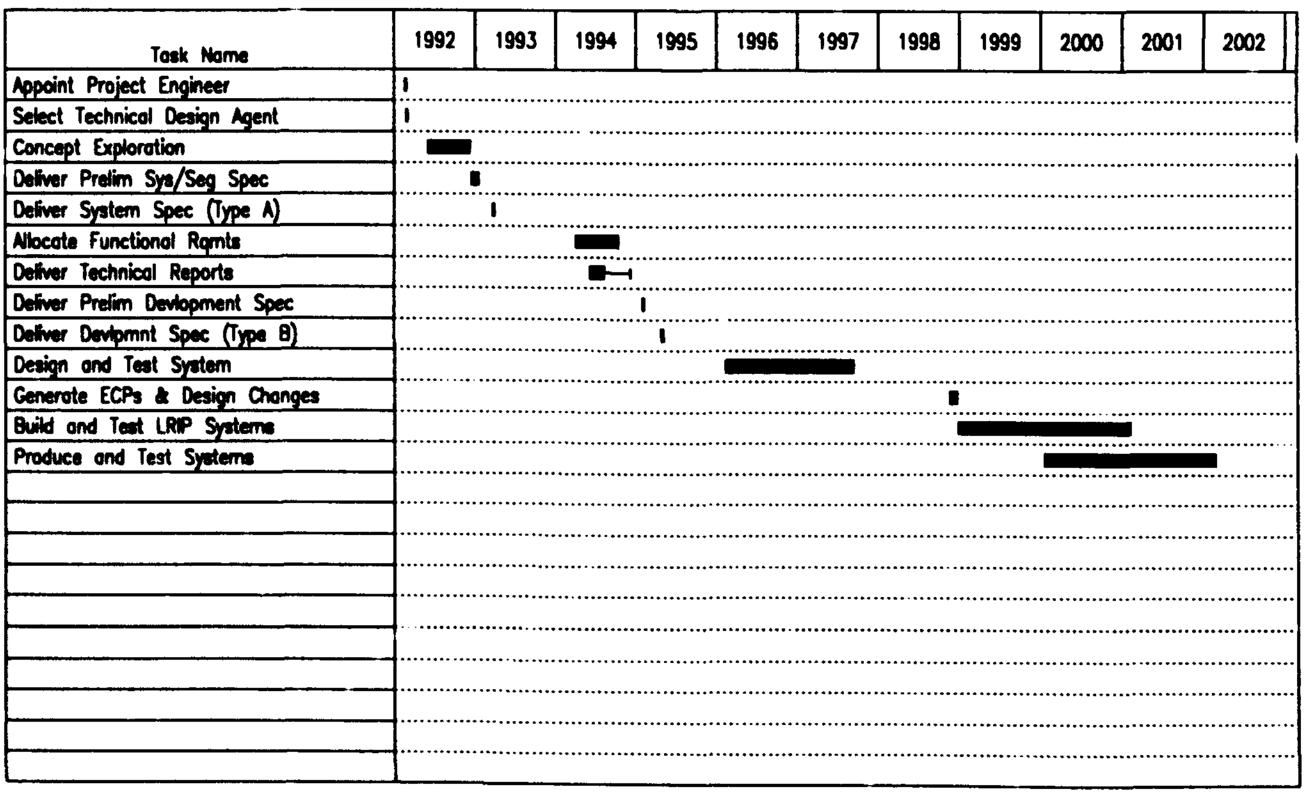
COMPUTER RESOURCES PLAN
Figure 3



TECHNICAL MANUAL PLAN
Figure 4



SYSTEMS ENGINEERING PLAN
Figure 5



Let's now return to a discussion of solutions to the Program Manager's logistics problems.

1) Lack of Planning - Although the LRR templates and generic PMP were developed to assist the LRR team members conduct a more through logistics review, the templates offer the Program Manager a valuable planning tool that can quickly be adapted to meet the specific needs of the project. Within a few weeks of receiving authorization to begin a new program, or to modify an existing weapon system program, the PM, with help from the ILS management team and the systems engineer, can tailor the generic PMP to meet the specific requirements of the program. The knowledge base built into the generic PMP facilitates the development of a comprehensive, program specific ILS plan and program master plan.

2) Conflicting Plans - Integration of system engineering, budget and funding, acquisition planning and ILS into a single PMP eliminates conflicting plans. All participants share the same plan, the same schedule. The PMP includes all the sub-plans necessary to manage a weapon system acquisition program. With the addition of a background paragraph and a system description, the PMP provides computer generated Gantt charts, PERT networks and budget sheets necessary to satisfy most of the 50 odd plans required by current policy. At present the Acquisition Plan, the Test and Evaluation Master Plan (TEMP), the Navy Training Plan (NTP), and the Computer Resources Life Cycle Management Plan (CRLCMP) need to be packaged separately because they require approval *outside the program* office.

3) Non-Integrated ILS Plans - Integrating separate ILS element plans, paying particular attention to inputs to each task and outputs from each task has resulted in a very good logistics process model. ILS element specialists participated in the development of logistics element templates and the integration into a logical sequence of interrelated tasks. Experts in the post-production product support phase were also included on the integration team. The result is a fully integrated ILS plan where task durations are estimated and task dependencies are established.

4) Inadequate LRFP - As each task in the logistics template is tailored for a particular acquisition program, a bottoms-up cost estimate is developed. The estimate is linked directly to that task. When the task is rescheduled, the funding requirement to accomplish that task is automatically rescheduled. The program tasks and the attendant funding requirements are correlated on a one-to-one basis.

ADDITIONAL BENEFITS OF LRR TEMPLATES

1) Self-Paced Training - The LRR templates have unlimited usefulness to LRG/LRR team members, team leaders, logistics interns and other logistics and acquisition learners. The templates provide quantitative and qualitative descriptive information suitable for both personal and classroom use.

2) Standard PC & NDI Software - The LRR Templates operate on a standard MS-DOS PC with TIMELINE (tm) Program Management software.

3) Standard Interfaces - The LRR templates interface with standard database and spreadsheet software. This allows the template information to be shared with other Navy ADP systems.

4) Minimum Variance - Standardized templates provide a baseline acquisition process model. By using the standard templates the PM will minimize planning variance and improve the probability of weapon system acquisition program success. The acquisition program will be properly planned from the beginning.

5) Extensive References - Applicable instructions, directives and handbooks are referenced. Often specific paragraphs are highlighted and points-of-contact are listed in the templates. The PMP provides a very complete and accurate picture of the acquisition process and as such provides an understanding of the process that can't be gained by simply reading the applicable directives.

6) Flexibility - The templates are flexible. Tasks may be added, deleted or tailored for non-developmental items (NDI), small boats, or other product lines. The templates can be quickly updated when new or revised policy is received.

7) Cost Effective - No paper would be complete in today's environment without a discussion of affordability. The templates, if used by all NAVSEA Program Managers, have the potential of significant cost savings per year. The cost savings result from the fact that program offices will now be able to quickly and accurately develop ILS plans and many logistics element plans in-house, vice contracting out for this effort.

SUMMARY OF BENEFITS

1) Rapid and accurate program planning. [1]

2) Integration of tasks and funding requirements.

3) Standardized weapon system acquisition process model.

4) Facilitates process analysis and improvements.

5) Promotes understanding of weapon system acquisition

and attendant logistics support processes.

6) Flexibility to add, delete or modify tasks and milestones.

7) Models process changes before they are implemented.

8) Minimizes need for directives and instructions.

CONCLUSIONS

The elements of logistics, working in harmony with systems engineering, acquisition and funding processes will accomplish the NAVSEA goal of translating mission needs into high quality products and support systems for our customers...the fleet sailors.

[1] To obtain a copy of the LRR Templates, contact Mr. Dave Conley at (703) 607-1700.

U.S. NAVY INSENSITIVE MUNITIONS PROGRAM

Dr. Richard E. Bowen
Director, Insensitive Munitions Program

Mr. Donald M. Porada
Assistant for Technology,
Insensitive Munitions Program
(SEA 66I)
Naval Sea Systems Command

Mr. William G. Nevitt
Assistant for Insensitive Munitions Programs
NSWC / Indian Head Division

May 1992

Approved for Public Release
Distribution Unlimited

Abstract

In 1984 the CNO officially established the Navy Insensitive Munitions (IM) Program. The survivability of ships, weapon platforms and stockpiles would be improved by reducing the sensitivity of munitions, and the CNO issued the Navy's policy on IM. The Navy IM Program's mission is to direct and manage all Navy efforts in the development and transfer of IM technology to weapon developers. "Munitions" include all energetic devices, such as bombs, missiles, torpedoes, mines, pyrotechnics, demolition charges and special purpose devices. Insensitive munitions are defined as those munitions which reliably fulfill their performance, readiness and operational requirements on demand, but which minimize the violence of a reaction and subsequent collateral damage when subjected to unplanned heat, shock, or fragment impact.

This paper will discuss how the Navy IM Program affects weapons system design and development, as well as its impact on shipboard munitions stowage and ship survivability. Insensitive munitions technology development concentrates its efforts on significantly improving the weapon systems' overall IM performance. Continuous programs on propulsion, warhead, and ordnance system responses are showing measurable progress.

LIST OF TABLES

NOTATIONS/DEFINITIONS/ ABBREVIATIONS

IM	Insensitive Munitions
IMAD	Insensitive Munitions Advanced Development
NAVSEA	Naval Sea Systems Command
WSESRB	Weapon Systems Explosive Safety Review Board
IMC	Insensitive Munitions Council
OPR	Office of Primary Responsibility
PM	Program Manager
PBX	Plastic Bonded Explosive
FCO	Fast Cook-Off
SCO	Slow Cook-Off
BI	Bullet Impact
FI	Fragment Impact
SD	Sympathetic Detonation

BACKGROUND

The importance of mitigating the reactions of our own weapon systems to heat, shock, and impact while in storage, transportation and staging configurations has been an issue demanding the attention of many agencies, both within and outside the Department of Defense, for many years. The tragic incident aboard the USS Forrestal in 1967, however, brought the issue into graphic relief. While conducting a strike sortie a U.S. aircraft carrier had come dangerously close to being sunk. Not as a result of enemy fire, but by its very own weapons, in particular MK 80 series bombs, which were cooking off in the intense heat caused by a flight deck fuel fire, which in turn had been the direct result of the inadvertant firing of a 5" Zuni rocket. In response to the incident the Navy initiated the "Cook Off" program, which sought to devise ways to prevent such a catastrophe from happening again. Another R&D effort, the Explosives Advanced Development Program, began looking more at ways to affect the sensitivity of explosive fills. Out of these efforts was spawned the present Navy Insensitive Munitions Program. Pursuant to recommendations contained in a Chief of Naval Operations Executive Board (CEB) Decision Memorandum, the official Navy policy on IM, OPNAVINST 8010.13 series was released in 1984.

SYSTEM DESIGN, DEVELOPMENT AND ACQUISITION

Sensitivity characteristics of a weapon system, whether an entirely new concept or a product improvement, affect not only the survivability of the weapon system itself in a hostile environment, but also the survivability of the launch platform, transportation vehicle, and storage facility. As such, sensitivity characterstics must be considered to be critical system characteristics. "System characteristics dictated by operational capability needs and constraints and critical to the successful operation of a new or modified weapon system shall be identified early and specifically addressed in cost-schedule-performance trade-offs. Critical system characteristics are those design features that determine how well the proposed concept or system will function in its intended operational environment. They include survivability; transportability; electronic counter-countermeasures; energy effiency; and interoperability, standardization, and compatibility with other forces and systems including support infrastructure"[1].

Within the Department of the Navy, policy on pursuit and effective attainment of the cost-schedule-performance trade-offs referenced above is contained in OPNAVINST 8010.13B: "All Navy munitions, in research and development or product improvement programs, shall be designed to meet the prevailing technical requirements for IM, as specified by COMNAVSEASYSCOM governing instructions. Operational capability must be maintained, but every reasonable effort must be made to meet operational requirements with the least sensitive energetic materials available"[2]. Development of such "least sensitive materials" and other mitigating techniques is the providence of the Navy Insensitive Munitions Advanced Development (IMAD) Program. IMAD Program focus and accomplishments, as they apply to specific weapon system progress, will be discussed later in this paper.

Although OP-35 maintains ultimate authority for approval or denial of requests by weapon program managers for waivers and certifications, execution and oversight of the Navy IM Program has largely been delegated to the Commander, Naval Sea Systems Command (COMNAVSEASYSCOM) as the lead systems command for energetic materials and explosives. The Navy IM Programs Divsion (SEA-66I), under the direction of the Deputy Director for Combat Systems (SEA-06), is COMNAVSEASYSCOM's management agent for IM. A representative from the Navy IM Program Office is a permanent voting member of the Navy Weapon Systems Engineering Safety Review Board (WSESRB), which provides input regarding system safety to the appropriate Navy acquisition authority before each Milestone decision. OPNAVINST 8010.13B also establishes a separate review mechanism specifically for IM. The Insensitive Munitions Council (IMC), chaired by OP-35, has authority to determine the IM status of a candidate weapon system, and to direct further action by the PM. The IMC also provides milestone decision input to the relevant Navy acquisition authority, usually ASN(RD&A). In this fashion IM characteristics of each system are reviewed at each Milestone, and are included in the cost-schedule-performance trade-offs mentioned above. "Each Office of Primary Responsibility (OPR), who is usually the Weapon Program Manager (PM), in all System Commands will incorporate appropriate technologies developed by the Insensitive Munitions Advanced Development (IMAD) Program, similar programs of other services, and/or DoD contractors in order to provide insensitive munitions to the fleet"[3].

NAVSEAINST 8010.5B also establishes oversight mechanisms and procedures. "Program Managers...must submit to the IM Office a POA&M or [as in the case of new weapons] a copy of the weapon's acquisition documentation such as the Operational Requirement (OR) or Test and Evaluation Master Plan (TEMP)....The acquisition documentation must include IM requirements and plans"[4]. NAVSEAINST 8010.5B directs managers to MIL-STD-2105A (Navy) for specific guidance regarding the conduct of IM testing.

DISCUSSION

The IMAD Program's primary mission is to develop the technology PMs need to make their systems IM. The IMAD technical approach to achieve this involves development of: less sensitive energetic materials; mitigation devices/concepts; and ordnance hardware design. The following are examples of each technique.

LESS SENSITIVE ENERGETIC MATERIALS.

Plastic bonded explosives (PBX) have been the primary area of emphasis in this category. They have been particularly useful in mitigating FI and BI reactions, but are also effective in mitigating cook-off reactions. Plasticization of otherwise sensitive materials such as RDX and HMX through use of elasto-polymeric binders facilitates better dissipation of shock, thus significantly raising the initiation threshold of high explosive materials when subjected to fragment or bullet impact. Where TNT would detonate, PBXs have burned or not reacted at all (e.g. bombs). Examples of other effective applications: the MK 98 Mod 0 Mine Neutralization Device uses PBXN-111 and passes all IM tests except sympathetic detonation; PBXN-103 is used in the MK 46 and MK 48 torpedo warheads, which also pass all IM tests with the exception of sympathetic detonation. With the introduction of continuous processing and injection loading techniques, the benefits of using PBXs are becoming available to submunition systems, such as BLU-97 used in Tomahawk.

MITIGATION DEVICES/CONCEPTS

The two basic categories of mitigation techniques are active mitigation systems and passive mitigation systems. Active systems are designed to react to changes in the ambient environment (e.g. temperature changes) to case-open a system before it has an opportunity to cook-off. An example is the Thermally Initiated Venting System (TIVS). A longitudinal linear shaped charge is incorporated into a rocket motor case design to function when a cook-off environment is sensed, thus splitting open the rocket motor case, negating the rocket motor case's confinement effect on the propellant, which is necessary for an explosion, detonation, or propulsive event to occur. Successful results have been seen using TIVS in the AMRAAM.

Passive mitigation systems incorporate into the weapon system design the ability of the warhead or rocket motor case to disintegrate or rupture prior to the point where a detonation, explosion, or propulsive event would normally occur given sufficient confinement. Concepts/techniques include strip laminate motor cases, stress risers, and preferential insulation techniques. Strip laminate case are helically wound strips of metal held together by adhesives strong enough to withstand the operating environment but which weaken when exposed to the high temperatures of a fast cook-off environment. The case basically melts and falls apart. The stress riser concept incorporates a "weak streak" in the bomb body or warhead case. The internal pressure of the explosive components reacting causes the bomb or warhead case to peel open before the high explosive has an opportunity to react under confinement.

ORDNANCE HARDWARE DESIGN

Areas of emphasis in the development of warhead technology have been case design/materials/fabrication; dual-explosive warheads; and warhead liners.

Case design/materials/fabrication concepts seek to utilize combinations of high strength materials as either layered metal cases (e.g. strip laminate rocket motor cases), ceramic coated cases, composite cases (i.e., metal and non-metallic materials), or cases utilizing reactive materials (e.g. aluminum alloys).

Dual explosive warheads utilize two explosives with significantly different output and vulnerability characteristics. An inner core of high performance/more sensitive explosive is surrounded by an outer cylinder of less sensitive material. Proper material selection and ratios of sensitive/insensitive explosives can maintain performance levels while taking advantage of the less sensitive explosive's shock attenuation characteristics. This concept is most applicable to large diameter missile warheads, although some experiments have been conducted on bomb configurations with some success.

The warhead liner approach utilizes 3 general techniques in warhead liner design to decrease the liklihood of violent reactions to IM stimuli. These three types of liner technologies are energetic liners, shock attenuating liners, and outgassing & inhibiting liners. Energetic liners incorporate an energetic material (e.g. a reactive metal) into the warhead liner design to enhance blast while reducing the vulnerability of the warhead to shock and thermal stimuli. Shock attenuating liners incorporate some form of shock protection into the liner design to reduce vulnerability to FI and SD stimuli. Outgassing and inhibiting techniques aim to provide a means for pressure release when a warhead is exposed to a cook-off environment.

In several instances all-up rounds with otherwise insensitive high explosive fills have failed IM tests due to the violent reaction of the fuze booster or some other part of the initiation train. Research into advanced initiation techniques attempts to solve this problem through development and implementation of novel initiation techniques and materials which reliably initiate the main charge while passing all IM criteria. Specific techniques include utilization of main charge explosives in fuze booster designs, imbedded plate boosters, laser initiation, and flying plate leads.

Materials,sheilding & container technology efforts emphasize the incorporation of advanced materials into the design of weapon system components to minimize thermal and shock responses; development of models to determine a system's need for additional protection to prevent inadvertent initiation and provide a means of estimating the degree of protection required; and packaging and container alternatives which will reduce vulnerability to all stimuli.

PROPULSION

In the area of propulsion, the R&D must mate the propellant development to a probable rocket motor configuration since the interaction between propellant and motor are so closely intertwined.

Recent emphasis within the IMAD Program has been placed on the development of minimum smoke and reduced smoke propellants for small diameter missiles such as Hellfire and Sidewinder. Because of the signature requirements, these types of propellants react very violently when subjected to IM test environments. The program is seeking to develop non-detonable propellants which maintain signature and performance requirements.

Another research area is booster propellants. The large diameter coupled with the small L/D and performance requirements make this a unique area of investigation. Research includes the development of tough propellants to withstand the shock loading of bullet and fragment impact. There is also an ongoing effort to design a composite booster motor case for a test vehicle.

Within the next two years, the data generated by generic propellants in generic hardware will be transitioned to specific systems through development contracts to industry and transition programs between IMAD and weapon program offices.

CONTAINERIZATION AND PACKAGING

The area of containerization and packaging has an impact on the entire life cycle of munitions: transportation, storage, and deployment. Simple changes in storage containers, packaging materials, configuration (e.g. nose-to-tail storage), and the use of barriers/shields can offer the weapon Program Manager a low cost, relatively simple solution to some IM problems. The logistics of size, weight, and handling characteristics need to be considered.

A computerized model has been developed to provide weapon systems developers with predictions of prompt detonation under fragment impact scenarios and can also be used to aid in the design of packaging schemes, including the inclusion of new materials, designs and shielding materials.

PROGRESS SHOWN IN WEAPON SYSTEM PROGRAMS.

General Purpose Bombs

Aerially deployed weapons have been around in some form since beginning of air warfare. The most widely used type of air ordnance, and the type whose presence in the fleet (on ships, air platforms, shore facilities, etc.) is most pervasive is the General Purpose Bomb. The Navy has identified the development of an IM certified General Purpose Bomb as its number one insensitive munitions priority.

The most recent generation of GP Bombs before the introduction of PBXs was the MK 80 series. The Navy MK 82 GP Bomb, which utilized a TNT/RDX-based fill (H-6), consistently deflagrated, exploded or detonated when exposed to IM stimuli during testing [5]. The BLU-111/B is an improved MK 82 GP Bomb filled with PBXN-109 instead of H-6. Introduction of the plasticized explosive as a main charge fill dramatically improved the IM performance of the bomb: in two out of three FCO tests the test unit burned; in two of two SCO tests the unit burned; in two of two BI tests the unit burned; and in two of two FI tests the unit burned [6].

Propulsion Systems

Within the current IMAD Propulsion Project several approaches are being pursued to reduce the sensitivity of solid motors to the IM hazard tests. These include the evaluation of postulates to reduce the violence of the reaction of encased solid propellants when exposed to the IM test stimuli, and the reduction of the confinement of the reacting propellants through the use of motor case concepts that degrade their pressure containment property when exposed to the thermal environment of the slow and fast cook-off tests. Propellant postulates being examined are: tough compositions that will not fragment or shatter when exposed to bullet or fragment impacts (fragmented propellant is hypothesized as the initiating source of high pressure explosions or stimuli and allow the reduction of the loading levels of sensitive solid oxydizers in the development of propellants; and the application of new, potentially less sensitive energetic ingredients in place of sensitive, current ingredients. The motor case investigations include the evaluation of a hybrid case consisting of a thin steel internal shell with venting strip openings that are sealed by overwrapping the steel shell with a fiber composite material that degrades at high temperatures. IN addition to these efforts, a joint project is being pursued with the Army (MICOM) to develop and demonstrate the feasibility of a minimum-smoke Hellfire technology rocket motor that meets the IM requirements. Also, to assist in the development of insensitive propellants and minimize development cost, small-scale tests are being developed. These include tests whose results can be used to predict the response of the propellant when encased to thermal and shock stimuli encountered in the IM hazard tests, and a methodology to predict the propellant's detonation potential during IM testing based upon small-scale shock tests, such as the Gap and Wedge tests.

Examples of recent achievements in the propellant/propulsion area are as follows.

Replacement of part of the sensitive ammonium perchlorate in the Tomahawk MK 111 aluminized HTPB booster propellant with a dense oxidizer (bismuth trioxide) provided a significant reduction in the violence of the response of the propellant encased in Sparrow motor hardware when subjected to slow cook-off and bullet impact environments compared with tests of the MK 111 propellant in the same hardware. This modification also resulted in a 6% improvement of the delivered density impulse (dense propellant concept) of the propellant.

Replacing the sensitive energetic plasticizer TMETN in a GAP reduced-smoke propellant with GAP azide energetic plasticizer overcame a friction sensitivity (processing) problem. The Air Force has shown considerable interest in this. Its contractor, who is developing a reduced-smoke propellant for the booster of a ducted rocket propulsion subsystem (a product improvement for AMRAAM) is currently evaluating this propellant for possible application.

System Application	Technology Drivers Hazard/Fix	Application
AIWS	SCO/Composite case	FY94-95
Advanced Rocket System	Various/AP-composite propellant	FY92
AMRAAM	Various/New propellant, joint effort USAF-ducted rocket booster	FY93-95
ASROC	Various/AP-composite propellant and advanced cases	FY95
Cruise (Tomahawk)	BI/Damage-resistant high-density propellant	FY2000
HARM	SCO/Advanced case, signature	FY96
Harpoon/SLAM	SCO/New burn-rate catalyst, propellant, case	FY92-98
Hellfire/HOMS	FI, SCO, multiple BI, signature/New propellant and motor to reduce detonation hazard, joint effort with Army	FY93
Phoenix	FCO, FI	FY94
Sea Sparrow	SCO, BI	FY92
Sidewinder/SRM	SCO, FI, BI/Signature, performance	FY94
SRAW	Various/Signature, advanced case	FY93
Standard	Various/Performance, high-density propellant	FY2000
TOW	Various/Signature	

TABLE 1. IMAD Propulsion Technology Applications

Investigation of CL-20, a recently synthesized caged nitramine, as a potentially lower sensitivity energetic oxidizer for minimum-smoke propellants has drawn the attention of the Short Range Anti-Tank Weapon (SRAW) Project Office. They have indicated a desire to fund performance and IM tests of the propellant developed using this ingredient.

The Multi-Mission Propulsion Technology Advanced Technology Demonstration Program is scheduled to be initiated in FY92. The plan is to use a composite case to meet IM cook-off requirements, as well as to obtain improved performance caused by the lower case weight compared to a steel case. It will be building upon the IMAD Program's composite case technology.

ON THE HORIZON

The ultimate goal of the IMAD propulsion project is to complete development and demonstration of new technology concepts and transition them to the Fleet. Some weapon systems to which these concepts could be applied are identified in Table 1.

SUMMARY

The IMAD Program approach to solving IM problems is a systems approach. The goal is to optimize the combination of favorable characteristics (e.g. insensitivity, performance, lowest cost) within the existing constraints (e.g. available technology, operational requirements, available funding) in pursuit of systems which will be certifiable as IM. Within the IMAD Program research is ongoing in many areas toward IM solutions. Some combination of several technology applications will likely be necessary in most cases to solve the vulnerability problems of a particular weapon system. The Navy IM Program Office is an available resource for weapon Program Managers to seek assistance in pursuit of IM certifiable systems.

REFERENCES

[1] DoD Instruction 5000.2, Defense Acquisition Management Policies and Procedures, February 23, 1991, p.4-C-1.

[2] OPNAV Instruction 8010.13B, Department of the Navy's Policy on Insensitive Munitions, June 27, 1989, p.1.

[3] NAVSEA Instruction 8010.5B, Insensitive Munitions Program Planning and Execution, December 5, 1989, p.2.

[4] Ibid.

[5] NWC TP 7077, Summary Report of Insensitive Munitions Testing of Bombs, Rockets, and Missiles, January 1991, p.27.

[6] Ibid., pp. 35-36.

ENVIRONMENTAL MONITORING AND OPERATOR GUIDANCE SYSTEM

Scott E. Robinson
Naval Architect
Submarine Hydrodynamics Branch
(SEA 55W31)
Naval Sea Systems Command

Andrew L. Silver
Research Engineer
Ship Dynamics Division
(Code 156)
NSWC / Carderock Division

May 1992

Approved for Public Release
Distribution Unlimited

Abstract

The seaward entrance to the Naval Submarine Base at Kings Bay Georgia is composed of a long shallow channel. Cost and impact on the environment made dredging a channel deep enough to accommodate safe passage of OHIO CLASS submarines in all expected seaways prohibitive. The Environmental Monitoring and Operator Guidance System (EMOGS) is a navigational aid system which was developed to measure inputs of wave, tide, and channel depth in the St Mary's entrance channel to Kings Bay and provide guidance to ship operators in the form of minimum expected underkeel clearance during transit. EMOGS uses a mathematical model to predict the ships' motions in a seaway. Environmental data is input into the model by sensors deployed near the Kings Bay channel.

EMOGS has been operating at Kings Bay since February 1989. This paper discusses the EMOGS development program, the system design and installation at Kings Bay, and other potential applications of the EMOGS technology.

LIST OF FIGURES

INTRODUCTION

The high cost of dredging, coupled with concerns about the environmental impact of major dredging projects has caused increasing concern over proper selection of depths for shallow water entrance channels to ports and harbors. Modern deep draft Navy ships require deeper channels than exist in some areas, particularly on the east and gulf coasts of the United States. Channel depth then becomes an important factor when considering where such ships can be homeported or serviced. The cost and environmental impact of dredging a channel to provide safe passage of a deep draft ship may be cause for rejecting a port which would otherwise meet all strategic and logistic requirements for the platform.

During the early planning stages of the Naval Submarine Base at Kings Bay GA (SUBASE) it was determined that the entrance channel would require dredging to accommodate OHIO CLASS ships. The Navy conducted a study to determine the channel depth required to safely operate the new submarines in the channel without restriction. The ships' draft in a seaway and potential weather in the Kings Bay area were examined. This study indicated that a channel depth in excess of 51 feet would be required to allow the ship to transit during all weather conditions. Channel depths of less than 51 feet would restrict the ship from transiting in certain weather conditions.

The cost of dredging the Kings Bay channel to 51 feet was determined to be prohibitive. Using a mathematical model to estimate the ships' motions in a seaway, the Navy predicted that a channel depth of 46 feet would provide safe transit during all but a few days of the year. During those few days wave induced motions of the submarine which would exceed channel depth. Engineers from David Taylor Research Center (DTRC) (currently David Taylor Model Basin, Carderock Division, Naval Surface Warfare Center) proposed the development of a navigational aid system which could monitor environmental conditions and provide warning to OHIO CLASS submarine operators when the risk of impacting the bottom during transit was high. Naval Sea Systems Command (NAVSEA) recommended the development of this system, the Environmental Monitoring and Operator Guidance System (EMOGS), to maximize ship

CLEARANCES FOR SSBN 726 IN 46 FOOT CHANNEL AND SSBN 640 IN 42 FOOT CHANNEL

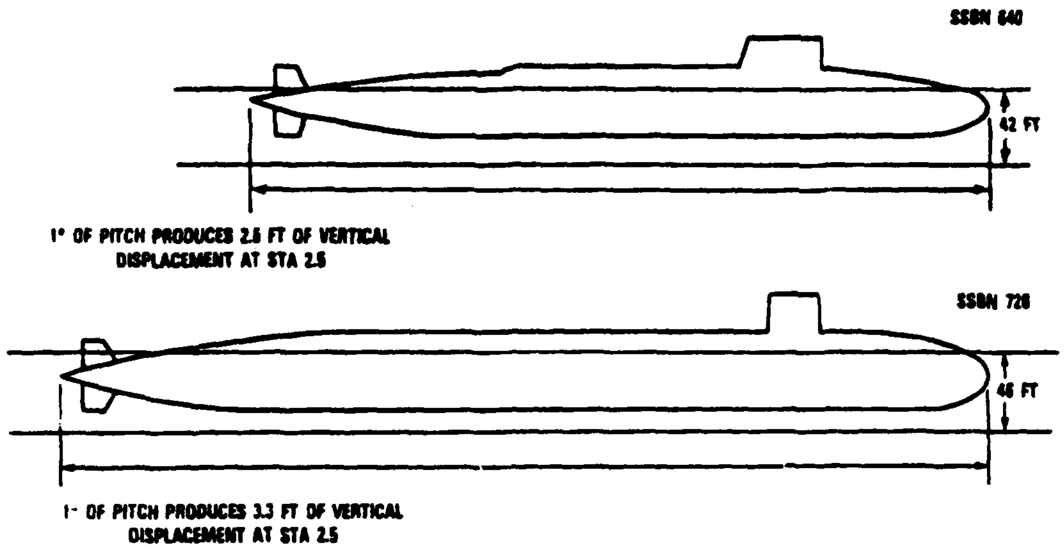


Figure 1. SSBN 726 vs SSBN 640 in a Shallow Channel

operations through the Kings Bay channel and reduce the risk of damage to the ships caused by impacting the bottom during channel transit.

Defining The Problem

Determination of the required channel clearance of a deep draft ship can be obtained by calculating the difference between the ship's draft and channel depth during the transit. The factors which determine ship's draft are: static draft, sinkage and trim, and wave induced motions.

A ship's navigational or static draft is the distance from the waterline to the deepest point on the keel when the ship is anchored, or at pierside. Although this number may be given as a constant, it can vary several inches with changes in water density. This means that water temperature, and more importantly water salinity will effect the ship's static draft. A ship's draft is also effected by the ship's loadout condition. In channels with limited clearance, careful consideration must be given to ship loadout and proper ballasting.

As a deep draft ship moves forward in a shallow channel, acceleration of the water beneath the ship's keel creates a "suction" effect which causes an increase in ship's draft, or sinkage, and a change in ship's trim. As the ship's speed increases so does the ship's sinkage and trim. In the case of the OHIO CLASS submarine, this effect can increase a ship's draft in a seaway by 18 inches or more. In some instances, ships transiting a channel at high speed can experience an increase in draft of several feet because of this effect.

Ship motions are generated by waves in the seaway. The motions in the vertical plane, heave and pitch, act to increase the ship's effective depth. This effect is exaggerated with longer ships where a small pitch angle can produce a greater depth excursion than on shorter ships. As figure (1) illustrates, a 1 degree pitch angle applied to the longer SSBN 726 CLASS submarine produces nearly a foot greater displacement at the ends of the ship than on the shorter SSBN 640 CLASS. The vertical displacement of the SSBN 726 submarine is primarily generated by long period waves, referred to as swell, from storms occurring east of the Kings Bay entrance channel. These storms produce the conditions which may restrict access to the channel.

The factors which influence the channel depth are: the project depth of the channel, the astronomic tide level, and the change in water level due to meteorological conditions. The first parameter, the project depth of the channel, is the minimum channel depth at mean low water (MLW). This depth is determined by the Corps of Engineers as the minimum depth that the channel can be before maintenance dredging begins. The channel depth at MLW can vary depending on sediment accumulation and dredging conditions and schedule. Sediment accumulates in the channel because shear forces on the sea bottom generated by waves and currents cause bottom sediment nearshore to move into the channel. Periodic surveys and maintenance dredging are required to control channel depth.

The second factor which effects channel depth during a transit is astronomic tide level. The average tidal range at Kings Bay is approximately 6 feet. Extreme astronomic tides, caused by periodic alignments of the planets of the solar system, can increase or decrease water levels by an additional 2.5 feet. The 12 mile channel length and consequently long transit time means that the tide level changes measurably during a transit. This change in tide level must be accounted for to provide a precise picture of ship clearance as it transits the channel.

The third parameter in determining effective channel depth is the effect of meteorological factors on water depth. A long duration of high or low barometric pressure can raise or lower water levels. Local onshore or offshore winds can also cause setup or setdown of the local water. Combined, the phenomena are called the meteorological tide and can effect the local water level by 2.5 feet. Meteorological tide can be estimated using rules of thumb to determine the effect of measured winds and pressures, or the tide can be measured directly.

The summation of all of these factors will determine a ship's net effective clearance, the smallest underkeel clearance expected during a channel transit. EMOGS enables ship crews to assess the risk of touching the channel bottom during a transit by evaluating environmental conditions and providing this clearance information.

SYSTEM DEVELOPMENT

A number of steps were performed in the development of EMOGS. First, an understanding of the dynamics of the environment was necessary in order to determine the critical parameters for calculating the effective channel clearance of the OHIO CLASS submarine. Second, the equipment required for obtaining the environmental data and operating EMOGS was selected. Third, the computer model of predicting the surfaced submarine motions was developed. Finally, model testing and full scale validation efforts were undertaken to verify the math model simulation of motion.

Environmental Studies

The water depth of the channel to the Naval Submarine Base at Kings Bay, Georgia is dynamic. As mentioned previously, water depth varies according to the fluctuations of a number of environmental parameters including sedimentation, astronomic and meteorological tidal levels, and wave height. Before EMOGS was installed, it was important to acquire an understanding of the range of values that each of the environmental parameters would be expected to have. Therefore, studies were conducted to monitor each of these important parameters and determine the range of values that would be expected to occur. A channel survey program was performed between 1988 and 1990, reference (1). This program collected bottom profile survey data of the channel. These data were analyzed to determine the "controlling depth", the 99th percentile shallowest depth, and the minimum and maximum depths. An attempt was also made to statistically predict the amount of sediment accretion in the channel due to storms. This was done by correlating the difference in the channel depths before and after the storm with the wave energy measured by wave buoys near the channel. However, because the storm data were not complete enough to calibrate the model, this effort was not incorporated in EMOGS.

In addition to the channel sedimentation, EMOGS required an accurate prediction of the astronomic tide and the range of values associated with the meteorological tide, or water level variation primarily due to extremes in wind speed and barometric pressure. Data from 1987 through 1989 were collected from a tide gage set up near the channel by the Corps of Engineers. These data were used to calibrate astronomic tidal constituents in a tide prediction computer program. In addition, these tide data were used to obtain a range of meteorologic tide values by obtaining the residual between the predicted and measured tide.

The final environmental study involved determining the wave pattern over the length of the channel. This was accomplished by installing three underwater pressure sensors at the seaward end of the channel, the turn and near the jetties at the landward entrance. Data were collected by these gages for two years. After examining the data, it was determined that the waves diminished only slightly as they approached the jetty area. Therefore, the waves near the entire length of the offshore portion of the channel could be well represented by buoys placed at the seaward end of the channel and at the turn.

Equipment Selection/Design

The hardware associated with the EMOGS central station at the Squadron 20 Operations Office consists of four wave measuring buoys, an IBM Personal Computer (PC) compatible, and a MicroVAX Workstation. Of all this equipment, the most attention was placed on the wave measuring buoys. Since EMOGS is a near real-time system, the buoy systems had to meet several specific criteria. The most important of these criteria were the following. First, the buoys must be able to collect and record directional wave data. Second, reliable real-time communication, Ultra High Frequency (UHF), between the buoys and shore must be able to be established for distances of up to 12 miles. Third, the buoys had to have the capability of satellite communication in the event that there was some disruption in the UHF link. Fourth, the buoys must be able to process the wave data on board to both minimize the communication time between the buoys and shore and enable satellite communication. Fifth, the buoys must be both stable enough so as not to capsize in the steep nearshore wave regime, and the mooring line flexible enough so that it would not effect the motions of the buoys. Sixth, a location sensor must be available so that the buoy can be tracked if it is cut from the mooring line. Finally, the buoy must be large enough so that it would not be stolen or damaged by boat and ship traffic in and around the channel. The one buoy system able to meet the criteria at the time of selection was Seatex A/S of Trondheim, Norway. The IBM PC compatible was required to act as the receiving station of the wave data from the buoys.

All of the EMOGS calculations are performed on the MicroVAX workstation. This computer was chosen because both its hardware and operating system allowed for multiple jobs being run and up to four users logged in at the same time. The hardware was composed of a 156 Megabyte hard disk, a 6 Megabyte memory, a tape cartridge backup, a color monitor, a hard copy printer, and eight serial ports. The serial ports are for user login and environmental data input. The operating system was VMS, the Digital Equipment Virtual Memory System. VMS allowed up to four ports being activated at the same time. For example, a remote station user at the Submarine Group could call in to the computer to obtain the latest EMOGS data while new wave information was being transferred to the VAX from the PC. Both jobs can occur simultaneously without interruption.

Math Model Development

The prediction of wave-induced ship motions is dependent upon calculating the appropriate motion transfer functions. These transfer functions are defined as the magnitude of ship motion per unit wave height that the ship encounters. The motion transfer functions are dependent upon the ship to wave encounter period and direction. The underlying theory used in creating the motion transfer functions for the surfaced OHIO CLASS submarine assumed that it behaved the same in waves as a surface ship. Accordingly, the computer program that predicts surface ship motions, the Ship Motion Program (SMP) (Meyers et al 1980, reference (2)), was used after it was modified to accommodate the horizontal stern planes of the submarine (McCreight and O'Dea 1990, reference (3)). SMP calculates the motion transfer functions through the two-dimensional strip theory approach for deep water conditions. Because the submarine transits in shallow water, the velocity potentials used in SMP had to be recalculated to reflect that condition. The shallow water velocity potentials were, therefore, determined outside of SMP (reference (3)) in a three-dimensional panel program and output into a file which could be read by SMP. The motion transfer functions were output into a file organized by ship to wave direction, ship speed, and critical wave modal periods.

During the EMOGS calculations, the appropriate transfer function is combined with the directional wave spectrum to yield the variance of the vertical displacement through the following equation:

$$\sigma_j^2=\int_0^{2\pi}\int_0^{\infty}S(\omega,\mu)|H_j(\omega,\mu)|^2 d\omega d\mu \tag{1}$$

where σ_j, is the vertical variance at either the bow or stern of the ship, S is the directional wave spectrum, and H is the motion transfer function for vertical displacement. This vertical displacement transfer function is a result of combining the heave, vertical up and down motion, transfer function, z, and the pitch, angular up and down motion, transfer function, θ, in the following way:

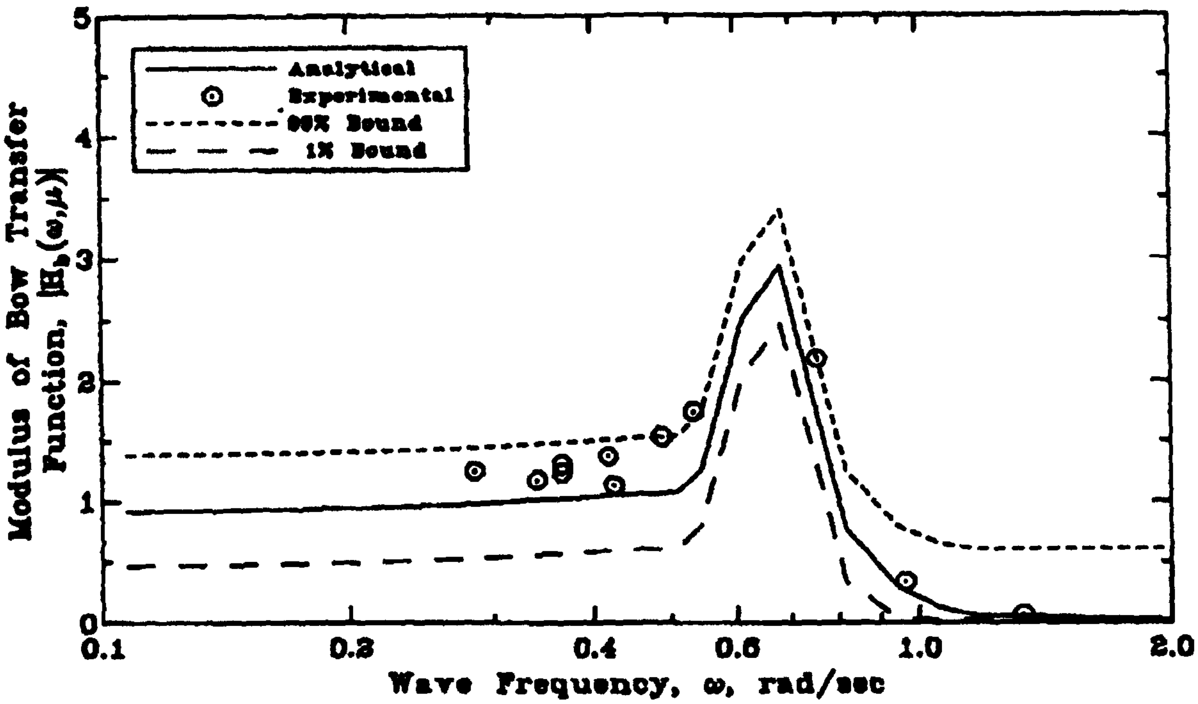
$$H_j=z+X_j\theta_j \tag{2}$$

Model Testing and Full Scale Validation

The predicted vertical displacement calculations were calibrated through shallow water model testing, and validated through a comparison with full scale data. The specifics of the model experiment were explained in Jones and Crown, 1988, reference (4). Briefly, a 1/25th scale model of the OHIO CLASS submarine was brought to the Waterways Experiment Station in Vicksburg, Mississippi and tested in a shallow water tank which simulated the depth of the entrance channel to the SUBASE at Kings Bay. The model was outfitted with sonic probes to measure both the waves as they approached the model, and the motions during the experimental run. The heave, pitch and vertical displacement transfer functions were obtained from the experiments using regular waves, and compared against the transfer functions that were calculated from the math model. An example of the results are shown in figure (2).

The math model transfer function predictions were validated by obtaining full scale measurements of the submarine movements in the channel as it passed by the two wave measuring buoys. This effort was documented in Silver and Dalzell 1991, reference (5). Briefly, each time an OHIO CLASS submarine transited the dogleg portion of the channel past the buoys, the heave velocity and pitch motions were recorded by the internal navigation system, ESGN. The vertical displacement record was determined from those recorded motions, and compared against the motions generated from the math model transfer functions and the recorded wave spectra from the buoys. The results of this validation are shown in figure (3) and reveal that the motions predicted within EMOGS result in larger magnitudes, by approximately 20 percent, than those measured. This over prediction provides a measure of safety for the overall EMOGS calculation.

Speed 12 knots, Beam Waves (μ= 90 deg)



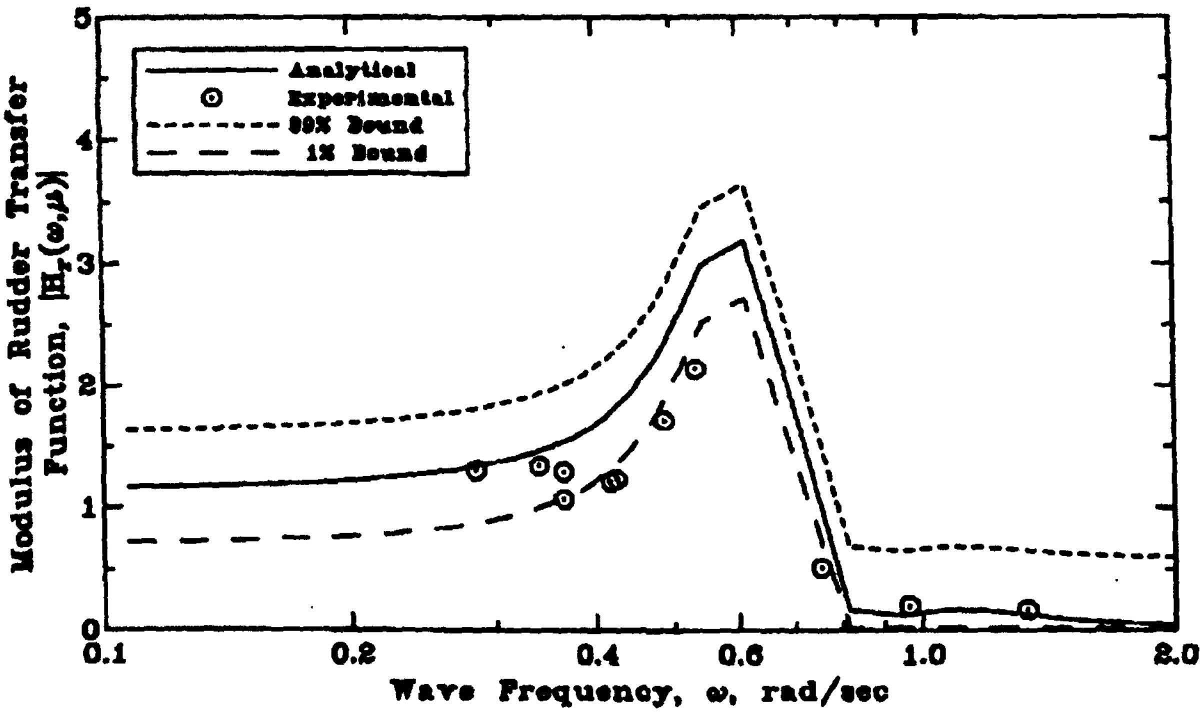


Figure 2. Comparison of Calculated Transfer Functions to Model Test Results.

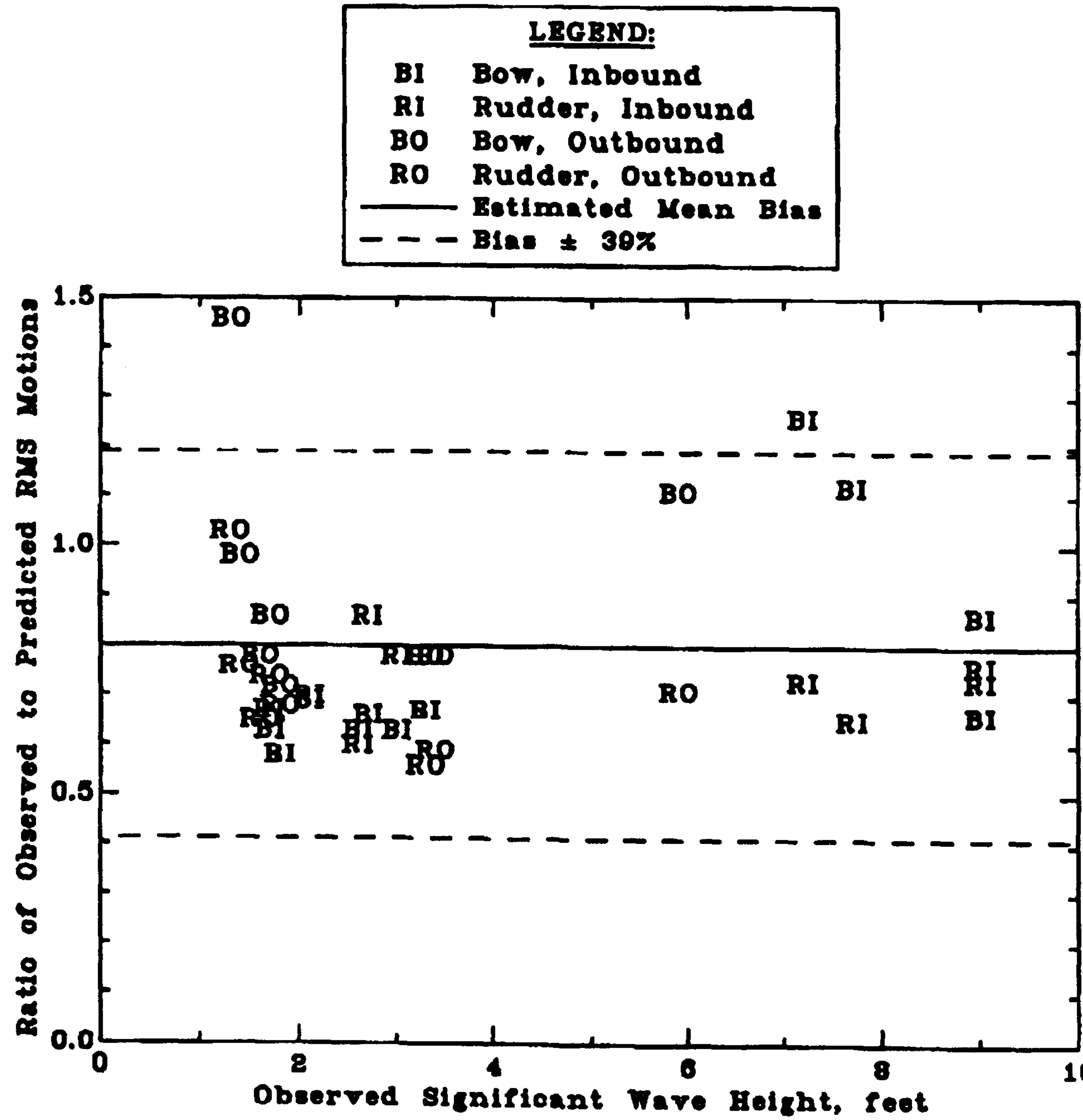
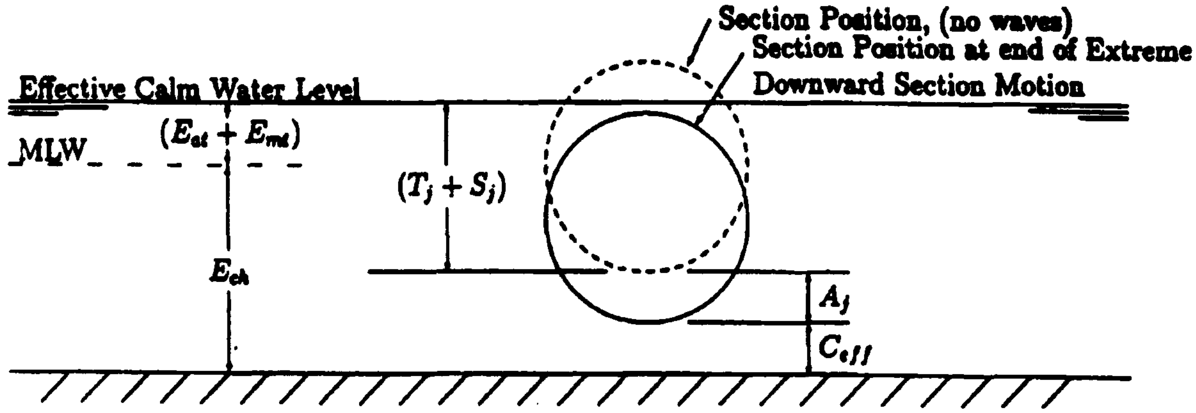


Figure 3. Comparison of Calculated Transfer Functions to Measured Trials Data

SYSTEM CONFIGURATION

Once the preliminary steps for development were accomplished, the system could be put together as a tool for the user. First, the end user of the system required to know the predicted net effective clearance between the submarine keel and the channel bottom during the transit, C_{ef}. EMOGS obtains this solution by summing the effective water depth of the channel during the transit and the predicted extreme vertical displacement of the submarine. As previously discussed, each of these factors are influenced by several parameters. As shown in figure (4), the effective water depth in the channel is dependent upon the channel depth at mean low tide, E_{cl}, the astronomic tide, E_{at}, and the meteorological tide, E_{mt}. The extreme vertical displacement of the submarine is calculated from the static draft in salt water, T_p, the sinkage and trim at speed, S_p, and the motions allowance, A_y. All of these parameters are summed to obtain the effective clearance according to the following equation:

NET EFFECTIVE CLEARANCE, C_{eff}



$$C_{eff} = E_{ch} + E_{at} + E_{mt} - T_j - S_j - A_j$$

where: E_{ch} = Minimum Channel Depth, T_j = Static Draft (SW)
E_{at} = Minimum Astronomical Tide, S_j = Underway Sinkage
E_{mt} = Meteorological Tide, A_j = Motions Allowance

Figure 4. Factors Influencing a Ship's Clearance in a Channel

$$C_{eff}=(E_{ch}+E_{at}+E_{mt})-(T_j+S_j+A_j) \quad (3)$$

EMOGS obtains each of these parameters in the following way. The effective channel depth at mean low water is obtained from the latest Corps of Engineers channel survey results. The data from the survey are input to a statistical computer program which calculates the "controlling depth" of 5 reaches of the channel as shown in figure (5). The "controlling depth" is defined as the 99th percentile shallowest depth. All depths shallower than the controlling depth are also identified and input into EMOGS as sediment hotspots. The astronomic tide level for the channel during the transit is predicted from a tidal algorithm based on 37 astronomic tidal constituents. These constituents have been calibrated by empirical data obtained by a real time tide gage installed by the Corps of Engineers near the channel. The meteorological tide is determined by obtaining the real-time tide data from the Corps of Engineers gage and obtaining the residual between it and the predicted tide level for the time of transit.

The factors composing the extreme vertical displacement are considered next. The static draft of the submarine in salt water is input by the EMOGS user and is usually given as the fully loaded design draft. The sinkage and trim value for the submarine in shallow water is dependent upon the predicted transit speed and is obtained from an EMOGS database. The final parameter making up the predicted extreme vertical displacement of the submarine within EMOGS is the motions allowance, A_j. This parameter is computed by first obtaining the motions variance through combining the motion transfer functions for the predicted speed and heading of the submarine during the channel transit with the measured directional wave spectra as in equation (1). The motions allowance is then statistically derived by the following equation (Ochi, 1973, reference (6)):

$$A_j=\sigma_j\sqrt{2\ln\left[\frac{L_r\sigma_{vj}}{2\pi a U\sigma_j}\right]} \quad (4)$$

where σ_j is the rms motion at the bow or stern, σ_{vj} is the time derivative of the rms motion, L_r is the length of the channel reach or series of reaches for which the allowance is being

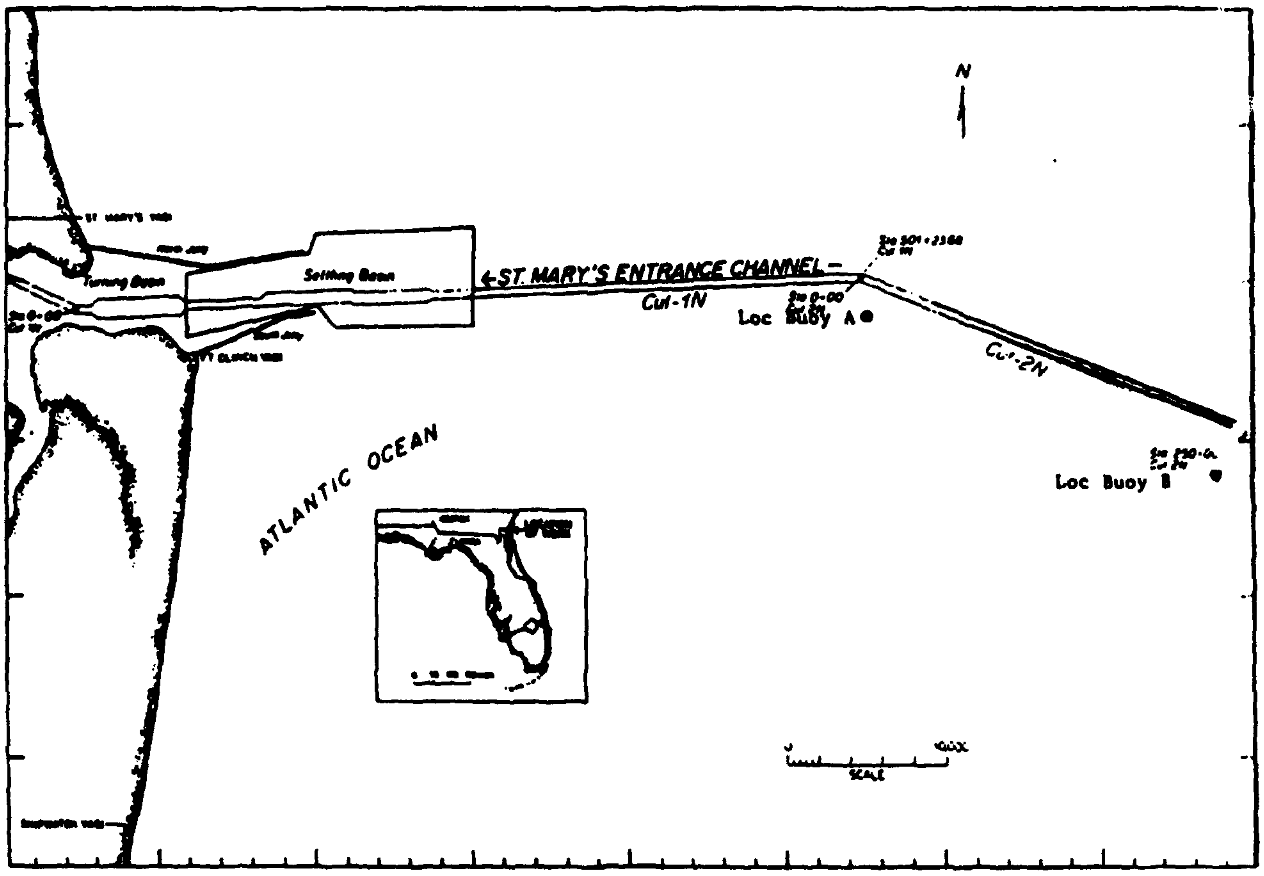


Figure 5. Location map of Kings Bay entrance channel and wave measuring buoys

calculated, U is the mean speed of the submarine during the time in the each channel segment, and is the risk parameter which determines the frequency of exceeding the motion allowance. The risk parameter within EMOGS is set to be 1 in 100 or that out of 100 downward excursions of the submarine during a transit, one would be greater than the calculated allowance. The motions allowance is therefore defined as the extreme vertical displacement at the bow and rudder tip that is expected to occur during an anticipated transit of the entrance channel. There are two major conditions on which the motion allowance is calculated within EMOGS. First, only one set of measured wave data from the buoys moored along the dogleg of the channel is used to describe the waves. Since the motions allowance represents an extreme vertical excursion, it is assumed that the wave conditions do not vary significantly over the length of the channel to effect this extreme. Second, the motions allowance is calculated for the dogleg reach, referred to as reach 1 in figure (5), and the remainder of the channel, reaches 2 through 5. This is to account for the change in relative ship to wave direction in the two sections of the channel.

UNCERTAINTY AND RISK IN THE EMOGS ADVISORY

In order for the end user of EMOGS to fully comprehend the meaning of the net effective clearance, an understanding of the uncertainties involved in obtaining the value and the risk the value represents is required. The net effective clearance is calculated by equation 3. The following two sections provide a summary of the investigation of the sources of uncertainty in the advisory, and the amount of risk that values of the advisory, net effective clearance, represent.

Sources of Uncertainty

Acquisition of the values of each of the components of equation 3 contribute uncertainty to the resultant EMOGS advisory. A complete and detailed uncertainty and risk analysis for the EMOGS advisory is included in Dalzell 1991, reference (7). As previously stated, the net effective clearance is the difference between the effective channel depth and the effective submarine vertical displacement. There are three parameters used in estimating the effective channel depth. The channel depth at mean low water is based on the controlling depth, the 99th percentile shallowest depth, from the most recent survey. The uncertainty of the controlling depth has been estimated at ±0.5 ft (0.15m) which takes into account both the errors due to data collection techniques and the sampling error. The astronomic tide level has an error stemming from the calibration of each of the 37 harmonic constituents of the tidal cycle. Since all of the measured tide data available from the Corps of Engineers tide gage covered only several non-continuous months, those constituents representing return cycles from one month to one year were not adequately calibrated. The estimate of the error band of the astronomic tide prediction for all parts of the offshore channel, therefore, was taken to be ±0.5 feet (±0.15m). The level of uncertainty in the meteorological tide estimate was also ±0.5 feet (±0.15m). This uncertainty stems from extrapolating the variable real time data, from the Corps of Engineers tide gage, to a future time when the submarine actually transits the channel. By taking the square root of the sum of the squares of both components of tide, the conventional error band for the tidal component is ±0.7 feet (0.2m). This figure corresponds to a ±2 standard deviations of the mean of a Normal distribution.

The effective dynamic draft in equation 3 consists of the static draft, underway sinkage and trim, and the predicted extreme vertical displacement due to wave-induced motions. Since the actual static draft is hard to measure, the design draft for the fully loaded condition is used in the EMOGS estimate. This figure can introduce a ±0.5 foot (±0.15m) uncertainty due to the difference between the true static draft and the design draft. The underway sinkage and trim table was predicted using a computer program after Beck, Newman and Tuck 1975, reference (8), and calibrated from the results of the model tests (Jones and Crown 1988, reference (4)). This value can be considered accurate to approximately ±0.5 feet (±0.15m) due to the scatter between the individual runs of the model test. Using the square root of the sum of the squares, as in reference (7), the static underway draft error band is approximately ±0.7 feet (0.2m). As with the channel depth, this corresponds to a ±2 standard deviations of the mean of a Normal distribution.

The uncertainty in the predicted wave-induced motions of the submarine as it transits the channel was determined by first examining the error bands of each of the components of motion, waves and motion transfer functions, then determining the contribution of uncertainty to the final underkeel clearance estimate. As previously mentioned, the transfer functions have been calibrated and validated by experimental model tests (Jones and Crown, 1988, reference (4)). Because of the uncertainties inherent in model tests, there is no absolute basis to completely validate the transfer functions. However, the scatter of the model test data generally fall within a 98% confidence band of the analytical transfer functions. Those data that lie outside this bound generally have values lower than the numerically derived transfer functions and therefore, as used in EMOGS, the predicted motions are more conservative. The wave data used in the EMOGS calculation are a representative sample of the wave conditions in the channel based on data collected for 20 minutes. These data are not the actual waves the submarine encounters during the transit, but are used as a representation of the general wave climate for the entrance channel. In addition, the wave data are collected along the entrance channel's dogleg and are assumed to represent the wave climate throughout the length of the channel. Each of the uncertainties of the motion transfer functions and the wave data were incorporated into an analytical model to determine the overall uncertainty of the predicted motions. The result of this uncertainty model compared the numerically predicted motions generated with "true" motions that account for each of the uncertainties in the transfer functions and measured wave spectra. From this analysis, it was concluded that the mean value of the ratio between the measured and estimated motion standard deviation was determined to be on the order of 1.2 with a scatter of ±30%. This result assumes no serious biases in either the wave spectra or the transfer functions. Analysis of the full scale measured vertical displacement resulted in a ratio between the measured and predicted mean motion standard deviation of 0.8 and a scatter of ±30% (Silver and Dalzell, 1991, reference (5)). The discrepancy between these ratios was not conclusively determined, but a study of the influence of the longcrested assumption in the uncertainty analysis yielded some resolution. For this case, measured buoy data for each transit were modified to represent longcrested waves propagating in the dominant direction. These waves were then used to generate predicted motions that could be compared with the observed motions from actual transits. When the two motions were compared, the resulting mean value of the ratio of standard deviations was 1.1. This figure is significantly closer to the analytical estimate than the 0.8 mean ratio that resulted from the original calculation using the measured directional spectrum. This result suggests that the bias in the predicted motions might be from the measured wave spectrum.

It has been recognized that, due to the random nature of the exciting force, the predicted vertical displacement of the submarine as calculated directly within EMOGS would not represent the maximum displacement in any one transit. Therefore, the vertical displacement is adjusted for the EMOGS output through a statistical formula developed by Ochi 1973, reference (6), to aid in predicting the magnitude of the extreme vertical displacement. A probability analysis was conducted by Dalzell 1991, reference (7), on the resulting extreme vertical displacement. This analysis determined the probability of occurrence of different values of the extreme vertical displacement according to the standard deviation, prediction bias and number of occurrences. The result of this study indicated that the number of encounters did not influence the probability distribution of the magnitude of the extreme excursions, but the bias and standard deviation of the sample of extreme values had a large influence.

Level of Risk in the EMOGS Advisory

The relative risk associated with the net effective clearance of the EMOGS advisory has been evaluated by Dalzell 1991, reference (7), based on the uncertainty analysis that was provided in the same reference. For this analysis, risk was defined as that portion of all possible transits under statistically constant conditions in which the minimum channel clearance would be negative. The risk model used for this definition computes the probability density of the minimum channel clearance and determines the area up to a minimum clearance of zero. Risk was mathematically defined as:

$$Risk = \int_{-\infty}^{0} p(C_K)\,dC_K \qquad (5)$$

where C_K is the minimum clearance and $p(C_K)$ is the probability density of the minimum clearance. The minimum clearance is defined as the algebraic sum of the nominal calm water clearance, C^*_{calm}, and the maximum downward excursion, Z_T. The calm water clearance is defined as the algebraic sum of the channel depths and the underway static drafts. Since each component of C^*_{calm} is assumed to be Normal, then C^*_{calm} is assumed to be a Normal process. Because the physical origins of these two parameters are statistically independent, the probability density function of the minimum clearance can then be expressed as a convolution (Papoulis 1965, reference (9):

$$P(C_K) = \int_{-\infty}^{\infty} p_c(C_K - Z_T)\,p_{ZT}(Z_T)\,dZ_T \qquad (6)$$

p_{ZT} in equation 6 is the probability density of the maximum downward excursion during the transit of a finite number of excursions and includes both the bias and scatter of the predicted vertical excursions as discussed in the uncertainty section of the paper. The risk was calculated in a stepwise approach by accounting for the particulars of the transit, the ship speed, channel length and course, channel depth and clearance, and the absolute channel water depth. The density of the calm water clearance and minimum clearance, $p(C_K)$, must then be calculated numerically in accordance with equation 6. Finally, the risk was calculated numerically in accordance with equation 5. This risk model was used to determine the numerical risk of the EMOGS net effective clearance. In this way, the operator could interpret the EMOGS output more effectively and provide the appropriate guidance. The risk model generated the risk for combinations of tide, ship speed, heading and 53 measured wave spectra for the channel project depth. Table (1) shows the results of this calculation.

Table (1)
Risk Level Definitions for Representative EMOGS Net Effective Clearances

EMOGS Net Clearance	Risk of Touching Project Depth	Verbal Assessment of Risk[1]
0 to 2 feet	*1 in 50 to 500*	*High risk*
2 to 4 feet	1 in 500 to 10^4	Mod. risk
>4 feet	less than 1 in 10^4	Low risk

INSTALLATION AND TRANSITION

The goal in developing EMOGS was to provide guidance to OHIO CLASS submarines from the first channel transit by the USS TENNESSEE entering Kings Bay. A schedule was developed which supported installation of EMOGS at Kings Bay prior to the arrival of the TENNESSEE in February 1989. To support this critical milestone, EMOGS equipment was installed in stages.

The first phase of the hardware installation took place in February 1989. Wave measuring capability was provided by deploying two wave buoys just south of the St Mary's inlet channel. An IBM PC compatible computer with the RTSCAN wave buoy software and a UHF receiver were installed at the Submarine Squadron 20 (SQUADRON 20) operations building. This allowed the squadron watchstanders to receive wave and weather information from the buoys. Installation of the wave measuring system was completed by assembling two additional wave buoys and storing them in the SUBASE Port Services department (Port Services) maintenance area. This provided readily deployable back-up buoys in the case of failure of a deployed buoy. The two additional buoys also provided a means by which buoys could be rotated off of deployment so that routine maintenance could be performed. In this way the system could be maintained at peak performance and provide 100% reliability.

In lieu of the ship motions prediction software, SQUADRON 20 watchstanders completed net effective clearance calculations by hand, using the method outlined in the EMOGS HANDBOOK, reference (10). The EMOGS HANDBOOK described the principles behind EMOGS, and provided the method and tables required to complete a ship clearance prediction using the wave information provided by the buoys. In this way, watchstanders developed an understanding of the principles used to develop an EMOGS advisory. They also became proficient at completing EMOGS calculations by hand. This became the back-up method for producing an EMOGS advisory in the case of failure of the MicroVAX computer.

EMOGS quickly demonstrated its effectiveness. During early transits of the TENNESSEE, the ship was able to operate safely in seaways which would have been considered unsafe using older less precise clearance prediction techniques.

The first version of the EMOGS ship motions software, EMOGS 1.0, was completed and installed at SQUADRON 20 operations in June 1989. With the installation of the software, watchstanders at SQUADRON 20 could now get a computer prediction of net effective clearance for OHIO CLASS ships just prior to channel transits. The EMOGS advisory reports became valuable information to the squadron and ship crews when making decisions about channel transits. Upgraded versions of the software were installed periodically throughout the 3 year installation/transition period. The upgraded versions contained enhancements such as wave prediction capability (24 and 48 hours in advance), the ability to measure meteorological tide directly in lieu of using rules of thumb based on wind and barometric pressure measurements, and the installation of two EMOGS remote stations at Port Services and Submarine Group 10, reference (11).

Neither DTRC nor NAVSEA were equipped to maintain or operate EMOGS for the life of the system. For this reason it was important to get the support of the SQUADRON and the SUBASE at Kings Bay and designate responsible operators and life cycle managers at Kings Bay. SQUADRON 20 was selected to operate the system, and SUBASE Port Services Department was designated as the system life cycle manager. It was vital that the transition program could ensure that the personnel at Kings Bay were able to maintain and operate EMOGS without the assistance of DTRC or NAVSEA. To accomplish this, a comprehensive transition program was developed which would gradually phase station personnel into greater and greater responsibility for the system during the three year installation/transition period. This was realized by providing extensive training, publishing several technical manuals and a training video on operation and maintenance of EMOGS, meeting with station personnel on EMOGS logistic support, and assisting in the development of budgetary requirements for the system.

Training: A full time EMOGS operator was not provided to Kings Bay by DTRC during the transition period. Instead, SQUADRON 20 watchstanders were provided extensive operator training during each installation phase of EMOGS. This training ranged in scope from several hours to several days and furnished SQUADRON 20 personnel with the skills needed to complete the operating tasks required for that phase of the system.

During the deployment of the EMOGS wave buoys, training sessions were held for EMOGS operators at SQUADRON 20 which demonstrated the use of the EMOGS HANDBOOK and RTSCAN buoy software. By the end of the buoy installation watchstanders at SQUADRON 20 operations could read the information provided by the buoys and use it in hand calculations to provide an advisory to OHIO CLASS ships transiting the channel.

When EMOGS 1.0 software was installed on the EMOGS MicroVAX a few months later, watchstanders were trained to use the EMOGS system to generate a submarine advisory. In addition, a SQUADRON 20 system manager was designated and provided with in-depth training on the EMOGS software. By the end of the system installation period watchstanders could use EMOGS to provide submarine advisories and the system manager could complete routine file maintenance functions. The system manager was also able to complete first line trouble shooting and correct system problems independently or with assistance by phone from DTRC engineers.

As each EMOGS enhancement was installed, operators were trained in the new system functions. In addition, training and review was provided in areas of interest to the operators or system manager.

Port Services personnel were trained in life cycle maintenance of the buoy system through involvement in buoy deployment and each buoy maintenance cycle during the three year transition period. In this way, personnel responsible for buoy maintenance learned many of the tasks required to maintain the buoys first hand. In addition, formal training sessions were provided to teach Port Services personnel how to complete specific inspections on contractor maintained hardware. A short buoy maintenance video was also developed, providing a visual reference for maintenance personnel. Port Services demonstrated their ability to independently maintain the buoy system by completing a buoy maintenance during the transition period without the aid of DTRC or NAVSEA personnel.

Documentation: To provide complete documentation for the system, a series of manuals was developed in addition to component manufacturer owner's manuals. These new manuals addressed EMOGS software, and the specific application of the EMOGS hardware. A listing of all the documentation provided as part of EMOGS is listed in appendix A. Two of the documents, Environmental Monitoring and Operator Guidance System (EMOGS) Integrated Logistic Support Plan (ILSP), reference (12), and Environmental Monitoring and Operator Guidance System (EMOGS) Overall Technical Description, reference (13), provide a quick summary of the system set up, maintenance, operation, and logistic support requirements. The documents can be used as a "road map" providing readers with an overview of topics pertinent to EMOGS and referring readers to other EMOGS documents for detailed information.

Logistic Support: The system's primary logistics requirements come from maintenance of the SEATEX wave buoys. The buoys are battery operated, with a six to eight month battery supply. Therefore, maintenance must be completed on each buoy every six months. This was accomplished by replacing the deployed buoys with those in storage. Buoys are then serviced and stored on shore at a small buoy maintenance facility located at Port Services. Buoy maintenance was staggered so that one buoy would be replaced every three months.

The buoy electronic design is proprietary to SEATEX and requires special training by SEATEX for certification to maintain the components. Rather than train either civilian or military Kings Bay personnel, NAVSEA recommended maintaining buoy electronic components using a maintenance contract. This would provide consistent service for the buoys at a reasonable cost. It would also eliminate a need to provide costly periodic training and retraining to SUBASE personnel.

A maintenance contract for the buoys was awarded to SEATEX following the deployment of the buoys at Kings Bay and was used to maintain the buoys throughout the transition period. The contract was transferred to the contracting officer at Kings Bay during the final option year. This provided the SUBASE with a vehicle to maintain the buoys during the station's first year of maintenance responsibility.

During the transition period, Port Services personnel were trained to complete the COTR functions and the non-contract maintenance for the buoys. In addition, copies of the buoy maintenance contract were provided to the SUBASE supply department so that they could become familiar with the contract requirements. Several meetings were held with SUBASE personnel to assist them in preparing to accept the awarded maintenance contract and develop a follow-on to that contract after it expired.

The transition period was also used to adjust the requirements for the buoy systems. Although the buoys had been used for many years in the North Atlantic, the Kings Bay deployment taxed the systems differently than was previously experienced. The transition operating period was used to establish mooring line replacement intervals, adjust battery requirements, and determine hull and electronics maintenance requirements in the new environment. The maintenance requirements necessary for the Kings Bay deployment of the buoys were specified in the ILSP, reference (12). This document became the primary reference for maintenance of the buoy system at Kings Bay.

Also developed during the transition period was a listing of buoy spare parts which should be maintained at Kings Bay to provide immediate repair capability. This list was incorporated into the ILSP. A complete stock of these parts was provided to the SUBASE at transfer of the system to the station.

Using and maintaining the EMOGS system for three years during the installation/transition period provided a good history of the operating and maintenance costs for the system. Consequently, detailed, historically based estimates for the EMOGS annual costs could be provided to the SUBASE before transferring the system. The cost estimates were detailed enough to allow the SUBASE to determine baseline funding and additional costs for emergency or unexpected repairs. The cost estimates were also used by the SUBASE in trade-off studies to determine whether certain maintenance functions could be completed more cost effectively by contract or using station personnel.

POTENTIAL APPLICATIONS OF EMOGS TECHNOLOGY

There are many applications for EMOGS technology. The most direct applications are EMOGS navigational aid systems for other ship classes. By altering ship specific coefficients in the EMOGS models, the system can provide clearance information to surface combatants, non-combatants, other submarine classes and even commercial vessels.

Mr Silver will present a paper to the American Society of Civil Engineers at the "Ports '92" conference (reference (14)) which will discuss commercial applications of the system. His paper addresses the use of EMOGS as an aid in cargo offloading operations. EMOGS can be used to determine the maximum cargo load which can be carried into ports serviced by shallow channels. This reduces cargo handling and shipping costs. Such a system could also be used by the Navy, providing clearance information during cargo and ordinance loading operations in areas serviced by shallow channels.

By reconfiguring EMOGS to provide maneuvering information, pilots operating large ships in ports with strong currents or channels with several tight turns can be provided with the ships' maneuvering characteristics. EMOGS can be a tremendous tool to aid navigation under these circumstances.

EMOGS technology can provide valuable, cost saving information to port and channel design. The models created during the early stages of EMOGS development allowed the Navy to reduce the depth requirements of the 12 mile St Mary's Inlet channel by 5 feet. This resulted not only in a substantial reduction in the cost of construction, but also a substantial reduction in maintenance costs. These same principles can be applied to other channel designs. By using information which is specific to the environmental conditions and ships operating in the channel, clearance models can be developed during the early stages of channel design. In this way channel depth can be optimized. A channel can be designed to provide safe operating conditions at a shallower project depth than would be considered using more conservative design methods.

EMOGS can also be used to reduce maintenance dredging costs of operating channels. Ship clearance information can be used to aid in optimizing dredging schedules, reducing dredging costs. Optimizing dredging schedules has the additional benefit of minimizing the effect of dredging on ship operations and the environment.

Finally, EMOGS technology can be used to provide shallow water operating guidance to ship crews. OHIO CLASS ships are provided with Allowable Wave Height curves which provide the crews with clearance information based on channel depth, wave height and direction, and ship speed. This information allows the ships' captains to evaluate a seaway and determine the risk of touching bottom during the transit of a shallow channel. Similar curves can be developed for other deep draft vessels.

CONCLUSION

The installation of EMOGS at Kings Bay GA has reduced the risk of OHIO CLASS ships touching bottom during channel transits, and has substantially reduced channel construction and maintenance costs. The EMOGS system has become an important part of Kings Bay submarine operations. Application of this technology to other ship classes can optimize shallow water operations and reduce dredging costs at Navy ports.

LISTING OF EMOGS DOCUMENTS

1. Wavescan User Manual, Seatex A/S, Trondheim, Norway, Revision No. 003/89, 20 Jan 89.
2. RTSCAN User Manual, Seatex A/S, Trondheim, Norway Rev. No. 0004/89, 13 Nov 1989.
3. "Hippy 120 C Mark II Sensor Manual," Datawell bv, Laboratorium voor Instrumentatie, Haarlem, Netherlands.
4. Digital Equipment Corporation, Maynard, Mass., "MicroVAX 2000 Owner's Manual," EK-MVXAA-OM-OO1, Jan 1987.
5. Digital Equipment Corporation, Maynard, Mass., "TK50 Tape Drive Subsystem; User's Guide," EK-OTK50-UG-004, Feb 1986.
6. Digital Equipment Corporation, Maynard, Mass., "MicroVAX 2000 Hardware Installation Guide," EK-MVXAA-IG-OO1, Jan 1987.
7. Digital Equipment Corporation, Maynard, Mass., "Installing and Using the VT330/340 Video Terminal," EK-VT3XX-UG-OO1, Mar 1987.
8. Digital Equipment Corporation, Maynard, Mass., "Installing and Using the LA75 Companion Printer," EK-OLA75-UG-002, Dec 1986.
9. Zenith Data Systems Corporation, St. Joseph, Mich., "Z-248 PC Series Computers Owner's Manual," 1986.
10. Dalzell J.F., U.T. Lee and A.L. Silver, "Environmental Monitoring and Operator Guidance System (EMOGS) Automated System User Guide Version 2.0," DTRC SHD-1283-10, Oct 1990.
11. Dalzell, J.F., and U.T. Lee, "Environmental Monitoring and Operator Guidance System (EMOGS) System/Programmer Reference Version 2.0," DTRC SHD-1283-11, Oct 1990.
12. McCreight, W.R., and J.F. O'Dea, "Transfer Function for a Surfaced Submarine in Shallow Water," DTRC SHD-1283-08, July 1990.
13. Dalzell, J.F., "Environmental Monitoring and Operator Guidance System (EMOGS) Uncertainty and Risk Analysis," DTRC SHD-1283-07, Jan 1991.
14. Silver, A.L. and J.F. Dalzell, "Environmental Monitoring and Operator Guidance System (EMOGS) Comparison of Predicted and Measured Submarine Motions," DTRC SHD-1283-12, Jan 1991.
15. Silver, A. L., Dalzell, J. F., Dolan, R., Aubrey, D., Lee, W. T., "Environmental Monitoring and Operator Guidance System (EMOGS), User Handbook," DTRC/SHD Report No. 1283-02, 1989.
16. Silver, A. L., Foley, E. W., "Environmental Monitoring and Operator Guidance System (EMOGS), Integrated Logistic Support Plan (ILSP)," DTRC/SHD Report No. 1283-13, 1991.
17. Silver, A. L., "Environmental Monitoring and Operator Guidance System (EMOGS), Overall Technical Description," DTRC/SHD Report No. 1283-16, 1991.
18. Dalzell, J. F., "Environmental Monitoring and Operator Guidance System (EMOGS), Uncertainty and Risk Analysis," DTRC/SHD Report No. 1283-07, Jan 1991.

REFERENCES

[1]. Aubrey, D. G., McSherry, T. R., Spencer, W. D., "Sedimentation Study Environmental Monitoring and Operator Guidance System (EMOGS) Kings Bay, Georgia 1988-1990 Final Report," WHOI Technical Report No. WHOI-91-17, 1991.

[2]. Meyers, W. G., Applebee, T. R., Baitis, A. E., "User's Manual for the Standard Ship Motion Program, SMP," DTNSRDC Report No. SPD-0936-01, Sept 1981.

[3]. McCreight, W., O'Dea, J. F., "Motion Transfer Functions for Surfaced OHIO Class Submarines in Shallow Water," DTRC Report No. SHD-1283-08, July 1990.

[4]. Jones, H. D., Crown, D. E., "Shallow and Deep Water Seakeeping Experiments with Model 5398 Representing the Trident Submarine," DTRC/SHD Report No. 1283-01, Oct 1988.

[5]. Silver, A. L., Dalzell, J. F., "Environmental Monitoring and Operator Guidance System (EMOGS), Comparison of Predicted and Measured Submarine Motions," DTRC/SHD Report No. 1283-12, Jan 1991.

[6]. Ochi, M. K., "On Prediction of Extreme Values," Journal of Ship Research, Vol 17, 1973.

[7]. Dalzell, J. F., "Environmental Monitoring and Operator Guidance System (EMOGS), Uncertainty and Risk Analysis," DTRC/SHD Report No. 1283-07, Jan 1991.

[8]. Beck, R. F., Newman, J. N., Tuck, E. O., "Hydrodynamic Forces on Ships In Dredged Channels," Journal of Ship Research, Vol 19, No. 3, 1975.

[9]. Papoulis, A., Probability, Random Variables, and Stochastic Processes, McGraw-Hill, New York, 1965.

[10]. Silver, A. L., Dalzell, J. F., Dolan, R., Aubrey, D., Lee, W. T., "Environmental Monitoring and Operator Guidance System (EMOGS): User Handbook," DTRC/SHD Report No. 1283-02, 1989.

[11]. Dalzell, J. F., Lee, W. T., Silver, A. L., "Environmental Monitoring and Operator Guidance System (EMOGS): Automated System User Guide, Version 2.1," DTRC Report SHD-1283-14, 1991.

[12]. Silver, A. L., Foley, E. W., "Environmental Monitoring and Operator Guidance System (EMOGS), Integrated Logistic Support Plan (ILSP)," DTRC/SHD Report No. 1283-13, July 1991.

[13]. Silver, A. L., "Environmental Monitoring and Operator Guidance System (EMOGS) Overall Technical Description," DTRC/SHD Report No. 1283-16, Sept 1991.

[14]. Silver, A. L., "Environmental Monitoring and Operator Guidance System (EMOGS) for Shallow Water Ports," Proceedings of the Ports '92 Conference, in press.

Note: Many of the above documents are not available in open literature.

POST-INSTALLATION ANALYSIS IN A JOB SHOP ENVIRONMENT

Mike Bolles
Head, Program Planning and Contol Ofice
Naval Shipyard Management Group
(SEA 072)
Naval Sea Systems Command

May 1992

Abstract

The purpose of this paper is to discuss post-installation analysis (also referred to as post-audit) in the context of engineering economic analysis and to discuss the various methods by which post-installation analysis can be accomplished. The importance of post-installation analysis (henceforth referred to as PIA) within the Department of Defense is underscored by the fact that during a 1989 audit of DoD's management of capital investments, the General Accounting Office found that post-installation analysis was not being performed within the DoD. As a result, recent Assistant Secretary of Defense, Comptroller (ASD(C)) guidance on Defense Business Operating Fund Financial Policy directs the Services to perform PIA on all capital investments justified wholly or partially on the basis of economic considerations. Although the mandate now exists, the ASD(C) guidance does not offer any methods for implementing the requirement. Given the lack of guidance from DOD on how to accomplish PIA and a general lack of information on the subject in contemporary engineering economic literature, this paper will attempt to fill these voids. This paper will first discuss the purpose of PIA, especially in terms of its role in rational economic decision-making, followed by a discussion of the various methods which can be employed to undertake PIA given different types of investment situations. Before proceeding further, however, it needs to be stated that what makes PIA different than other performance measurement systems is that PIA focuses exclusively on the investment project and its actual performance. Consequently, plant-level performance measurement systems often can not serve to derive PIA data because most plant-level performance measurement systems do not correlate specific resource inputs to specific product line outputs. Moreover, even if such a refined performance measurement system exists, unless an investment is used exclusively in a specific industrial process to produce a specific product line, plant-level performance data is generally incapable of capturing the actual performance of a specific investment decision. As will be demonstrated throughout this paper, performing PIA in a job shop environment is more difficult than performing PIA in a production line environment. This is because of the small production lot sizes in a job shop environment, including lot sizes of one. Consequently, whereas production line performance data can often be collected from work center level financial data, performance data for job shops often has to be collected manually on the shop floor.

THE PURPOSE OF PIA

In the broadest sense, there are three general purposes which PIA can serve. First, inasmuch as PIA serves to verify and validate whether the costs and benefits used in an initial money flow model of a prospective project are in fact borne out after the project is implemented, PIA focuses accountability on the adequacy of the initial decision-making process. Therefore, one major purpose which PIA serves is to hold decision-makers accountable for their actions. The rationale underlying this purpose is that is it possible for decision-makers to be lax in fully analyzing the data which goes into a money flow model because the decision-makers are already predisposed to undertake a given investment alternative. In such a situation, the initial economic analysis may be simply a "smoke and mirrors" analysis to justify a preferred course of action. By comparing the adequacy of the initial decision-making model against the actual performance of a chosen investment alternative, PIA serves to "keep the process honest," in that if decision-makers know up front that they will be held accountable to the results of their decisions, they will be more inclined to attempt as accurate of an analysis as possible in the first place. The second purpose which PIA serves has to do with subsequent decisions once an investment is made. A large number of capital investment decisions entail the purchase of new equipment which has residual or salvage value. On the secondary/used equipment market, after an initial sharp decrease in value once the equipment is placed into operation, the salvage value of equipment generally decreases at a constant rate until the equipment begins to approach its useful technological life, at which time the salvage value drops off dramatically. Therefore, once an investment is made, how long the item should be retained in operation can affect the overall present equivalence value of the investment. For example, if it is demonstrated through PIA that an investment is not achieving the projected savings modeled in the initial money flow, the decision-maker is then faced with a follow-on decision to either retain the asset and generate as much benefit as possible (albeit, less benefit than was originally anticipated) or to abandon the project early so as to recover as much salvage value as possible. Consequently, inherent in most investment projects is a follow-on decision as to how best optimize the resulting benefits, notwithstanding the fact that sunk-costs have been incurred. Without data from PIA, this type of rational optimization can not occur irrespective of whether the operators of the equipment intrinsically recognize if the equipment is producing as expected or not. The third major purpose which PIA serves is to act as a feedback mechanism for future economic decision-making on subsequent projects. For example, the benefits of most machine tool projects are predicated to some extent on the projected increase in productivity of a new piece of equipment or industrial process over an existing piece of equipment or process. Often these productivity improvement projects are based on incomplete or estimated information such as prototype results, manufacturer's sales literature or industrial engineering projections. Whether a project ultimately achieves the benefits ascribed to it during the initial economic analysis is often based on whether the assumed productivity is realized. For most machine tools, increases in productivity generally occur through some combination of reduced setup time, decreased machining time, or reduced rejection/rework. Whether or not the benefits in these areas are realized depends on a number of factors which can not be determined during the initial analysis with complete certainty. For example, with Numerical Control (NC) machinery, the current work force may not be able to fully acclimate themselves to the major process change represented by the introduction of NC. Some machinists may even resist the introduction of NC and as a result the overall productivity of the new equipment may suffer. These types of intangibles can not be quantified with certainty during the initial analysis. Moreover, business volume and workload often can not be quantified with certainty, but are critically important in determining the overall benefits which the implementation of a investment alternative will achieve. Because of these types of uncertainties, engineers often model the data used in the initial analysis by using algorithms derived from actual experience previously gained from similar types of investments. Therefore, the quality of these parametric algorithms is critical and can be significantly improved when they are attenuated for actual performance as measured by PIA.

METHODOLOGIES FOR PERFORMING PIA

The effort to collect data to be used in PIA can range from the relatively simple to the relatively complex depending on both the nature of the investment being analyzed and the nature of the product or process with which the investment is associated. Specifically, the following taxonomy is useful for highlighting the different methodological approaches which can be used to accomplish PIA. On one axis of the taxonomy is the function which the equipment performs. In the broadest sense, there are two types of functions which equipment can perform, specialized functions and general purpose functions. Specialized function equipment are those which can accomplish only a single well-defined industrial process. For example, a gasket cutting machine is generally used to do only one operation: cut gaskets. On the other hand, general purpose equipment are those which can accomplish multiple industrial processes. Moreover, there often are numerous machines which have the capability to produce the product (in part or in total). For example, a machining turning center can be used to cut, shape, mill, bore and debur a variety of metals from aluminum to steel, but so can other machines such as lathes, milling machines and boring machines. The other axis of the taxonomy is the category of the product line being produced by the equipment. One category of product line is a unidimensional product line. An example of an equipment investment for a unidimensional product line would be a piece of equipment employed to machine only eight inch diameter ball valves. The other category of product line is a multi-dimensional product line. An example of an equipment investment for a multi-dimensional product line would be a piece of equipment employed to produce a range of products such as four, six, eight, and ten inch diameter ball and gate valves. Therefore, based on this taxonomy four combinations can exist:

(1) specialized equipment/unidimensional product line;

(2) specialized equipment/multi-dimensional product line;

(3) general purpose equipment/unidimensional product line; and

(4) general purpose equipment/multi-dimensional product line. Each combination of this taxonomy usually requires a different methodological approach in order to collect data for PIA. As such, each combination will be discussed in turn.

Specialized Equipment/Unidimensional Product Line.

This is usually the easiest combination by which PIA data can be collected. Because the equipment in this category performs a single function on a single product line, collecting equipment performance data can be as simple as measuring the quantity of output for a given period of time and dividing it by resource inputs (e.g., labor hours for the machine operator) minus any rework associated with the machine. Other inputs such as energy consumption can usually be derived by factoring the hours that the equipment is used in combination with the energy efficiency of the equipment. To illustrate, if a gasket cutting machine produces 10,000 gaskets in six months, then the productivity of the equipment can be calculated by dividing the number of units produced by the labor hours employed to derive a ratio of labor-hours-per-unit-produced. This ratio can then be compared with the same ratio associated with the previous way in which gaskets were cut prior to the introduction of the new equipment. The ratio between the new machine's labor-hours-per-unit-produced and the old process's labor-hours-per-unit-produced would represent the actual productivity increase for the new equipment. To take this example further, if the new machine produced 10,000 gaskets in six months with 1,010 direct labor hours, the labor-hours-per-unit-produced would be .101 hours per unit. If the previous process yielded 7,000 units per six months of direct labor, then its labor-hours-per-unit produced would have been .1442 hours per unit. Therefore, the new equipment can be seen to have a 42.8% increase in productivity relative to the older process. If the productivity assumption used in the the original money flow (which compared the present equivalence of the old method with the gasket cutting machine alternative) was 42.8% or greater, then the PIA would validate that the present equivalence of the gasket cutting machine was achieved relative to the old process (at least in terms of labor costs and benefits).

Specialized Equipment/Multi-Dimensional Product Line

The situation where there is a specialized piece of equipment which produces multiple product lines is more complex than is the case with a unidimensional product line. To use the gasket cutting machine example again, let it be assumed that the machine cuts three sizes of gaskets out of rubber and three sizes of gaskets out of a synthetic fiber material. The methodology employed in this situation would be similar to that employed in the unidimensional situation, except that the data need to be weighted to control for any variation in product mix. For example, Table One illustrates what the new gasket cutting machine produced in six months time.

Moreover, Table Two illustrates what the old process produced in six months time.

Table One

Product	Quantity	Labor Hours	Hours/Unit
Size 1, rubber	1500	125	.0833
Size 2, rubber	2000	160	.08
Size 3, rubber	5000	400	.08
Size 1, fiber	1000	100	.10
Size 2, fiber	2000	125	.0625
Size 3, fiber	1000	100	.10
Total	12,500	1,010	.0808

Table Two

Product	Quantity	Labor Hours	Hours/Unit
Size 1, rubber	1800	200	.111
Size 2, rubber	500	100	.20
Size 3, rubber	3500	400	.1142
Size 1, fiber	1500	100	.066
Size 2, fiber	1500	110	.073
Size 3, fiber	1000	100	.10
Total	9,800	1,010	.1030

Because of the shift in the gasket product line mix (both in terms of material and the numbers of each size gasket produced) and given that the direct labor-hours-per-unit-produced varies among the different product lines, it is unreasonable to simply average the two resulting total-hours-per-unit values to compare productivity. However, the two product mixes can be normalized simply by multiplying the individual hours/unit ratio of one of the product mixes by the quantity produced in the other product mix, and deriving the estimated labor hours that it would have taken the first process to accomplish the other process's workload. The ratio between the actual labor hours for the one process and the derived labor hours for the other process can then serve as the basis for measuring the productivity change between the two processes. By normalizing the product mix in such a fashion, the increase in productivity can be directly compared. For example, Table Three uses the hour/unit ratio per product line of the new machine multiplied by the product mix of the older process. Consequently, the new machine is projected to have been able to accomplish the workload of the old process in 813.15 hours as opposed to the 1010 hours required by the old process. Therefore, the productivity increase associated with the new equipment can be estimated at 24.4%.

General Purpose Equipment/ Unidimensional Product Line

Table Three

Product	Old Process Quantity	New Process Hours/Unit	New Process Derived Labor Hours
Size 1, rubber	1800	.0833	149.4
Size 2, rubber	500	.08	40.0
Size 3, rubber	3500	.08	280.0
Size 1, fiber	1500	.1	150.0
Size 2, fiber	1500	.0625	93.75
Size 3, fiber	1000	.10	100.0
Total	9800		813.15

It is under this situation that collecting data for PIA can become more troublesome than under the first two situations. This is because more than one piece of equipment normally can be used to accomplish the same industrial process when general purpose equipment is involved. Therefore, unlike the case with special function equipment, there is not a direct relationship in this case between a unique piece of equipment and a specific product line. For example, say that the new piece of equipment in question is a turning center which produces 8 inch gate values. The turning center represents the first step of an overall plant modernization. Prior to this procurement, the plant was laid out along functional machine tool lines. The steps of the industrial process require that raw stock be first turned down to the required diameter on a lathe, then the ends are milled, the center bored and the valve body deburred. To accomplish the required work, the plant had three lathes, two mills, a boring machine and a deburring machine. Once the new turning center is installed, it will be able to do all of the above operations without removing the stock. However, the single turning center is not capable of machining all of the throughput. Therefore, some valves had to be manufactured using the "old" four step process while other valves were manufactured using the new one step turning center process. Consequently, to undertake PIA, aggregate total outputs and inputs can not be simply factored to develop a hours-per-unit-ratio as was the case in the specialized equipment models. The best method to undertake PIA in this situation is to track specific valves or valve lots longitudinally through both the old and the new manufacturing processes. For example, for a given period of time, a representative sample set of valves requiring manufacturing would be identified. Each lot of similar values would be split such that half of them would be manufactured under the "old" four step process and half of them would be manufactured under the new turning center process. Measurements could then be taken as to total machining time (including intra-valve center transportation, set-up time and machining time) for each valve in each valve lot. Various methods may be available to collect these data. If a sophisticated Shop Floor Control System (SFC) exists such that processing time can be attributed to specific machine tools for specific product lots, then summary SFC data may be usable. However, few organizations have this sophisticated of a SFC system. A "manual" alternative would be to develop operator logs so that process time data can be collected for those valves or valve lots which are flagged as the sample set. Once the data are collected, the results are simply averaged. (Note: no numerical weighing is needed because each individual lot represents a homogeneous population.) Consequently, the difference between the two processes can be identified. For example, Table Four serves to illustrate this method.

Table Four

Lot Number	Lot Size (Split)	Total Machining Time (Old)	Total Machining Time (New)
1	32	5,760 minutes	4,439 minutes
2	25	5,625 minutes	4,065 minutes
3	41	7,749 minutes	6,001 minutes

From this data, the average machining time for the old process would be 195.2 minutes, whereas the average machining time for the new process would be 148.0 minutes. Therefore, this performance would indicated that a 31.9% increase in productivity was achieved between the old and new processes.

General Purpose Equipment/Multi-dimensional Product Line

The methodology which can be employed with general purpose equipment and a multidimensional product line is a hybrid combining the weighted average approach with the longitudinal study approach. The key factor to keep in mind while undertaking the general purpose equipment/multi-dimensional product line is that a balance must be struck to collect adequate information on the different product lines being produced by the process. In fact, one can conceptualize that what actually occurs is a series of discrete data collections for each major product line, which are then combined to develop a weighted measure of aggregate performance. The reason why this method can be conceptualized as a series of discrete data collections is that the sampling set is not the entire population of products, but a series of sampling sets, each representing a discrete product line. (This is also referred to as stratified or cluster sampling, where each "cluster" represents a discrete product line. The probability of any sub-set of the strata being picked must be proportional to the prevalence of the strata in the entire population). This approach must be taken because of the lack of homogeneity in the product line population. For example, say the the situation being analyzed is one where a turning center manufactures numerous types of valves, not just 8" gate valves as was postulated in the previous example. In this example, assume that the product lines were a "family" (in the Group Technology sense of the term) of various sized gate and ball valves. To collect meaningful data, each discrete product line would have to have a sample sub-set extracted from it. Each sub-set would then be split into two lots as was the case with the unidimensional product line methodology. Once actual machine performance data are collected, the results would be averaged together using weighted averaging techniques, where the weights assigned would be in direct proportion to the prevalence of the sampled sub-set in the total population of products. To illustrate, say that there are six discrete product lines as follows: 4" gate valves; 6" gate valves; 8" gate valves; 6" globe valves; 8" globe valves; and, 10" globe valves. Lots for each product line are then identified using representative sampling techniques. Machining data are then collected

Table Five

Product	Lot#	Split Lot Size	Old Process Machining Time	New Process Machining Time
4" gate	1	21	3,150 minutes	2,268 minutes
4" gate	2	20	3,005 minutes	2,109 minutes
6" gate	1	10	1,789 minutes	1,357 minutes
6" gate	2	15	2,423 minutes	1,987 minutes
6" gate	3	7	1,324 minutes	989 minutes
6" gate	4	10	1,903 minutes	1,443 minutes
8" gate	1	40	11,280 minutes	7,892 minutes
6" globe	1	25	4,768 minutes	4,001 minutes
6" globe	2	20	3,789 minutes	2,999 minutes
8" globe	1	50	14,321 minutes	10,156 minutes
10" globe	1	5	1,767 minutes	1,127 minutes
10" globe	2	10	3,183 minutes	2,432 minutes
10" globe	3	15	3,866 minutes	2,919 minutes

using operator logs for each sample set. Table Five illustrates the results.

For each Product line, Table Six shows the average processing time for the old and the new processes.

The percentage of each product sub-set relative to the valve center's overall product line mix is illustrated by Table Seven.

Therefore, by multiplying each product's average manufacturing time by the percentage of total production which each product represents, an aggregate average manufacturing time for both the old and new processes can be developed. In this example, the total average manufacturing time for the old process is 237.38 minutes while the total aggregate average manufacturing time for the new process is 168.29 minutes. Consequently, it can be determined that the new process represents a 41% increase in productivity over the old process. The main difficulty with this methodology is splitting the lot sizes so that both the old and the new process are used to manufacture the different product lines. To set this type of methodology in place requires very close coordination with production so as not to adversely affect the shop floor. However, with pre-planning, the adoption of this methodology is feasible in most industrial situations.

Table Six

Product	Old Process Avg Machining Time	NewProcess Avg Machining Time
4" gate	150.12 minutes	106.76 minutes
6" gate	177.11 minutes	137.52 minutes
8" gate	282.00 minutes	197.30 minutes
6" globe	190.16 minutes	155.55 minutes
8" globe	286.42 minutes	203.12 minutes
10" globe	352.64 minutes	215.93 minutes

Table Seven

Product	Percentage of Total Product Line
4" gate	18%
6" gate	16%
8" gate	20%
6" globe	16%
8" globe	16%
10" globe	14%

Dissimilar Product Lines

The above methods presuppose that the product line undergoing both the "old" and "new" process are fundamentally the same. Often an old piece of equipment is maintained in an operational status even after the new piece of equipment is put into service. In such cases, it is relatively simple to split product lots between the two processes or machines. However, in some cases the old process is discarded or the old equipment removed prior to the new process or equipment coming on line. In these cases it is absolutely critical that decision-makers plan out how they are going to approach PIA, especially in terms of how data are going to be collected. If the old process/equipment is going to be excessed, then performance data on this equipment must be collected prior to that time. However, situations can exist where the old equipment is taken out of operation before the new equipment operational while at the same time there is a fundamental change in the physical and/or metallurgical characteristics of the product mix being produced. As an example, assume that a production facility is going to replace an older machining center with a new turning center for manufacturing valves. The new piece of equipment will be installed in the same space which the old piece of equipment occupied. As such, the old piece of equipment will be placed out of operation and removed prior to the new equipment's arrival. Moreover, assume that the company is a subcontractor to a major shipbuilder and that its current contract calls for manufacturing a number of ball valves between four to twelve inches in diameter. The shipbuilder has recently placed a new advanced order with the plant, but this time is is for six to sixteen inch diameter ball valves. This order will begin to be manufactured after the new equipment is installed. Therefore, the company recognizes that the physical characteristics of the product mix to be manufactured on the new piece of equipment is fundamentally different than the physical characteristics of the product mix which has been manufactured on the old piece of equipment. Consequently, the product mix's physical characteristics vis-a-vis the manufacturing process must be normalized if meaningful PIA is to occur. One approach to solve this type of problem is to mathematically infer how the old piece of equipment would have performed on the new workload and to then compare the projected performance of the old piece of equipment against the actual performance of the new piece of equipment. The cornerstone of this methodology is to develop correlation coefficients for some readily available characteristics of the products being manufactured on the old machine and use these coefficients to infer how the old machine would have preformed on the new product mix.

Such coefficients can be developed through regression analysis. This is accomplished by first identifying key quantifiable characteristics of the product which can be modeled as independent (exogenous) variables to predict machine tool performance. The identification of the independent variables may take a number of iterations before key variables are found which can predict equipment performance consistently over the range of products produced. However, in this case let it be assumed that the variables of valve diameter and valve weight are discovered to adequately predict equipment performance, measured by set-up time and machining time. Once adequate predictor variables are identified, actual independent and dependent variable data are collected on a representative samples for the old product mix manufactured under the old process. For this example, the sample set includes twenty-two 4" to 12" ball valves. Each ball valve's diameter and weight are recorded, as well as the actual equipment set-up time and the time required to machine the valves on the old equipment. Once the data have been collected, regression coefficients are calculated (using Ordinary Least Squared (OLS) regression) which correlate the independent variables with each dependent variable (e.g., set-up time and machining time). Because it is not unusual for the relationships between these types of variables to be non-linear (for example, although the set-up time for an 8" valve is usually greater than the set-up time for a 4" valve, it is usually something less than twice as long) simple linear regression often provides a "poor fit" to these relationships, especially at the extremes of the variable range. Numerous methods are available to plot non-linear relationships. However, although the correlation is generally not linear, neither is it normally exponential. Usually the relationship has a "gentle" curve. One method to fit a non-linear correlation is to simply square the value of each independent variable and include them as additional independent variables in the OLS regression model. Table Eight illustrates the data base for this type of model. In it, set-up time is predicted by valve size, valve size squared, valve weight and valve weight squared. Also, these types of models generally work better when a constant is included (e.g., driving the slope through the origin usually skews the slope of the best fit line downward). The resulting OLS model for predicting set-up time on the old machine is: Old Machine Set-Up Time = 1.136 +(3.1518 * valve size) + (-0.0374 * valve size squared) + (.09357 * valve weight) + (-0.0000719 * valve weight squared). The Pearson's correlation (R squared) for this model is .9045. The resulting OLS model for predicting machining time on the old machine is: Old Machine Machining Time = 62.671 + (-0.4588 * valve size) + (0.9358 * valve size squared) + (0.09753 * valve weight) + (0.0005210 * valve weight squared). The Pearson's correlation for this model is .9472.

Once the regression coefficients are developed, the actual values of the independent variables can be used to predict both set-up and machining time. As shown in Table Nine, the model's predicted set-up and machining times can then be compared to the actual set-up and machining times. The deltas between the predicated valve and the actual value (e.g., residuals) should themselves be random; i.e., not correlated to any given values of the independent variables. If the residuals are not random, then there is a systematic bias in the model which may be skewing the results. Diagnostic tests such as those for heteroskedacity and autocorrleation should be employed at this stage (which is beyond the scope of this paper).

Once the regression coefficients are calculated and the residuals determined to be bias free, the model is filed for future use to support the PIA for the new piece of equipment. After the new piece of equipment is operational, similar data for the same independent and dependent variables are

Table Ten

NEW MACHINE

Valve Size	Weight	Actual Set-up Time	Actual Machining Time
6	50	22	70
8	75	32	100
6	55	20	75
10	160	33	150
14	180	45	180
16	260	45	220
12	190	38	190
8	70	26	95
6	45	22	65
12	200	32	170
12	170	39	180
16	245	53	200
10	185	29	160
8	80	20	90
8	65	31	110
8	70	28	90
10	170	32	165
14	200	55	210
8	75	22	85
14	225	50	210
8	70	20	90
16	225	80	240

Table Eight OLD MACHINE

Valve Size	Valve size Squared	Weight	Weight Squared	Actual Set-up Time	Actual Machining Time
8	64	65	4225	32	135
12	144	150	22500	45	220
6	36	50	2500	28	95
4	16	45	2025	20	80
8	64	75	5625	36	150
4	16	50	2500	19	65
8	64	65	4225	35	110
6	36	45	2025	30	90
12	144	220	48400	35	240
8	64	80	6400	33	135
4	16	40	1600	22	90
6	36	55	3025	27	100
10	100	180	32400	40	180
8	64	75	5625	30	120
8	64	60	3600	29	145
8	64	80	6400	32	110
6	36	50	2500	27	105
4	16	35	1225	19	85
4	16	45	2025	15	90
10	100	160	25600	40	200
12	144	190	36100	45	220
8	64	70	4900	30	120

Table Nine OLD MACHINE

Valve Size	Actual Set-up Time	Predicted Set-up Time	Actual Machining Time	Predicted Machine Time
8	32	32.6	135	127.4
12	45	44.3	220	218.3
6	28	25.4	95	99.8
4	20	18.7	80	81.3
8	36	33.0	150	129.1
4	19	19.1	65	82.0
8	35	32.6	110	127.4
6	30	25.0	90	99.1
12	35	35.7	240	238.6
8	33	33.2	135	130.0
4	22	18.3	90	80.5
6	27	25.7	100	100.5
10	40	35.1	180	186.1
8	30	33.0	120	129.1
8	29	32.4	145	126.6
8	32	33.2	110	130.0
6	27	25.4	105	99.8
4	19	17.9	85	79.9
4	15	18.7	90	81.3
10	40	37.2	200	180.6
12	45	40.2	220	229.3
8	30	32.8	120	128.3

collected for the new workload actually accomplished on the new piece of equipment. Table Ten illustrates the data for the new equipment used in this example. In order to compare the old equipment's performance relative to the new equipment's performance, the actual independent variable data recorded for the new workload are used to infer what the old equipment's performance would have been while manufacturing the new product mix. As such, the new workload's independent variable data are "plugged" into the old equipment's regression model. The resulting predicted values indicate what the old equipment's performance would have been on the new workload. These results can then be compared with the actual performance of the new equipment to determine the new equipment's relative increase in productivity. Table Eleven illustrates what the regression model infers the old equipment's set-up and machining times would have been for the new workload, as compared to the actual set-up and machining times for the new equipment.

However, it must be kept in mind that the regression model only projects a point estimate and is not 100% accurate in its predictive capabilities (i.e., the Pearson's correlation is not 1.0 for either model). Therefore, the actual performance of the old equipment — within a given statistical accuracy — is some factor plus or minus the point estimate generated by the models. In order to generate confidence intervals around each point estimated at 95% confidence (which is the norm for most statistical analyses), the standard error of the regression model is multiplied by 1.96 (which represents the number of standard deviations needed to achieve 95% confidence for a two-tailed test). The resulting confidence interval factor is then added to each point estimate to derive the upper confidence limit, and subtracted from each point estimate to derive the lower confidence limit. Consequently, for each data element, the model can be interpreted to mean that there is a 95% confidence that the actual inferred performance of the old machine in producing the new workload lies somewhere between the lower and the upper confidence limits (LCL and UCL, respectively). Because this example uses a multi-dimensional product mix, the results must be weighted in order to determine aggregate performance. Therefore, the average manufacturing time for each valve size strata is multiplied by the percentage of workload that each strata represents relative to the total new workload. Lower confidence limits are then factored into the aggregate performances for both set-up and machining time (it is not necessary to calculate upper confidence intervals because it is the minimum difference in performance between the old and new machines which is of interest — this minimum difference is reflected in the lower confidence interval). In order to determine aggregate performance, the composite set-up times and machining times are then added together. The results are shown in Table Twelve.

Table Eleven

	Old Machine		New Machine	
Valve Size	Inferred Set-up Time	Inferred Machining Time	Actual Set-up Time	Actual Machining Time
6	25.9	99.8	22	70
8	33.5	129.1	32	100
6	26.5	100.5	20	75
10	39.4	180.6	33	150
14	47.1	274.1	45	180
16	40.3	355.5	45	220
12	41.9	229.3	38	190
8	33.1	128.3	26	95
6	25.4	99.1	22	65
12	40.9	232.3	32	170
12	43.5	223.6	39	180
16	43.1	350.1	53	200
10	37.7	187.5	29	160
8	33.8	130.0	20	90
8	32.7	127.4	31	110
8	33.1	128.3	28	90
10	38.8	183.3	32	165
14	45.3	280.0	55	210
8	33.5	229.1	22	85
14	42.2	288.0	50	210
8	33.1	128.3	20	90
16	41.3	353.6	80	240

Once the results are calculated, validation of the original money flow can occur using the Present Equivalence method. (Note: for government activities, the Office of Management and Budget has established a discount rate of 10% to calculate money flows.) For example, let us assume that the original economic analysis indicated that the old machine had a yearly recurring production cost of $100K, an annual maintenance costs of $20K and a salvage value of $0K. Moreover, let us assume that the original economic analysis projected the new machine to have an initial investment cost of $100K, a yearly recurring production cost o^f^ $66K (e.g., a 34% improvement in productivity for the new machine

Table Twelve

Composite Avg Time New Machine	Composite Avg Time (At Point Estimate) Old Machine	Productivity Increase
183.9 min	243.3 min	1.323%
Composite Avg Time New Machine	**Composite Avg Time (At LCL) Old Machine at LCL**	**Productivity Increase at LCL**
183.9 min	212.5 min	1.155%

Table Thirteen

OLD MACHINE COSTS (ACTUAL)
(in thousands of dollars)

	Yr0	Yr1	Yr2	Yr3	Yr4	Yr5	Yr6	Yr7	Yr8	Yr9	Yr10
Manuf Cost	0	100	100	100	100	100	100	100	100	100	100
O&M Cost	0	20	20	20	20	20	20	20	20	20	20
Salvage	0	0	0	0	0	0	0	0	0	0	0
Invest	0	0	0	0	0	0	0	0	0	0	0
Net Cash	0	120	120	120	120	120	120	120	120	120	120

Net Present Equivalent Cost = $3,479

NEW MACHINE COSTS (PREDICTED)
(in thousands of dollars)

	Yr0	Yr1	Yr2	Yr3	Yr4	Yr5	Yr6	Yr7	Yr8	Yr9	Yr10
Manuf Cost	0	66	66	66	66	66	66	66	66	66	66
O&M Cost	0	10	10	10	10	10	10	10	10	10	10
Salvage	0	0	0	0	0	0	0	0	0	0	-20
Invest	100	0	0	0	0	0	0	0	0	0	0
Net Cash	100	76	76	76	76	76	76	76	76	76	56

Net Present Equivalent Cost = $1,634

Table Fourteen

NEW MACHINE (AT 32% PRODUCTIVITY IMPROVEMENT)
(in thousands of dollars)

	Yr0	Yr1	Yr2	Yr3	Yr4	Yr5	Yr6	Yr7	Yr8	Yr9	Yr10
Manuf Cost	0	68	68	68	68	68	68	68	68	68	68
O&M Cost	0	10	10	10	10	10	10	10	10	10	10
Salvage	0	0	0	0	0	0	0	0	0	0	-20
Invest	0	0	0	0	0	0	0	0	0	0	0
Net Cash	100	78	78	78	78	78	78	78	78	78	58

Net Present Equivalent Cost = $1,706,000

NEW MACHINE COSTS (AT 15.5% PRODUCTIVITY IMPROVEMENT)
(in thousands of dollars)

	Yr0	Yr1	Yr2	Yr3	Yr4	Yr5	Yr6	Yr7	Yr8	Yr9	Yr10
Manuf Cost	0	85	85	85	85	85	85	85	85	85	85
O&M Cost	0	10	10	10	10	10	10	10	10	10	10
Salvage	0	0	0	0	0	0	0	0	0	0	-20
Invest	100	0	0	0	0	0	0	0	0	0	0
Net Cash	100	95	95	95	95	95	95	95	95	95	75

Net Present Equivalent Cost = $2,377,000 relative to the old machine for any given workload), an annual maintenance costs of $10K and a salvage value of $20K. Moreover, let us assume a 10 year life for the new equipment. Consequently, Table Thirteen indicates the respective Present Equivalent cash flows for both the old and new machines over the ten year life of the new equipment. As can be seen, the original Present Equivalent cost for the old machine was $3,479,000 (at 10% interest), while the original Present Equivalent cost for the new machine was estimated at $1,634,000 (at 10% interest). Consequently, the Present Equivalent cash flows projected a $1,845,000 life cycle cost savings for the new machine relative to the old machine. However, given the PIA data, the actual performance of the new machine can be compared to the inferred performance of the old machine, as illustrated by in Table Fourteen. From Table Twelve, the relative productivity improvement between the new machine and the inferred performance of the old machine at the point estimate is only 32%, not the 34% assumed in the initial cash flow. Moreover, the old machine's inferred performance at the Lower Confidence Level indicates a relative productivity improvement of only 15.5%, vice 33%. The effect of these differences in productivity is a decrease in the life cycle Present Equivalence cash flow to $1,773,000 at a 32% increase in productivity and $1,102,000 at only a 15.5% increase in productivity. However, because the cash flow for the new machine is better than those for the old machine, the new machine can be considered to have resulted in a positive cash flow. Even with only a 15.5% increase in productivity, the difference would not have resulted in decision reversal.

POST-SCRIPT

This paper attempted to establish different methodological approaches for different investment scenarios. What is critical to understand is that any PIA must be preplanned and well thought-out. Decision-makers can not wait until new equipment is operational before envisioning how PIA will be accomplished (especially if the old equipment is being excessed). In sum, performing PIA is as much of an "art" as it is a science. Creativity and foresight must go into developing the PIA plan if meaningful analysis is to be forthcoming.